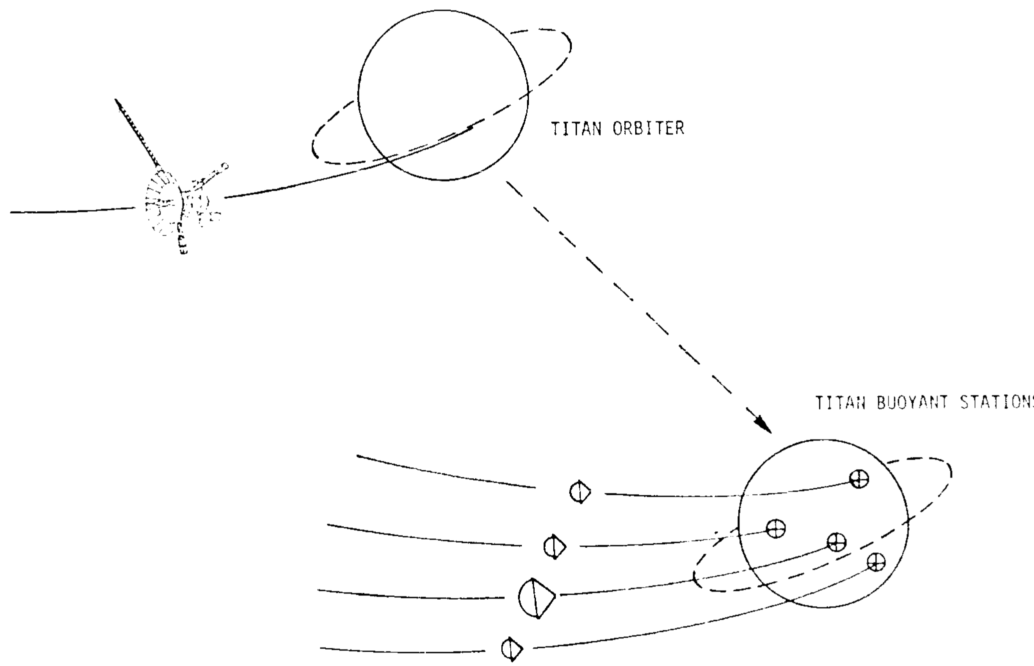
TITAN EXPLORATION WITH ADVANCED SYSTEMS

a study of future mission concepts



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TITAN EXPLORATION WITH ADVANCED SYSTEMS

A Study of Future Mission Concepts

by

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for

Solar System Exploration Division
Office of Space Science and Applications
NASA Headquarters
Washington, DC 20546

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FOREWORD

This study was conducted between January and July 1983 as part of the work performed by Science Applications, Inc. under Contract No. NASW-3622 for the Solar System Exploration Division, Code EL, NASA Headquarters. The total technical effort expended on this study task was 44 man-weeks. Results presented herein are intended to assist NASA planners and the planetary science community in assessing the requirements, capabilities and programmatic issues associated with science-intensive mission concepts for the advanced exploration of Saturn's largest satellite - Titan. The study was undertaken to support the Solar System Exploration Committee's (SSEC) focus on potential augmentations to the SSEC-recommended core program, and was presented at the SSEC Summer Study held in August 1983.

Alan Friedlander served as study leader for this effort. Very significant contributions were made by SAI Division 120 staff including Harvey Feingold, Steve Hoffman, John Jeffrey, Deanna Limperes, John Niehoff, Terri Ramlose, John Soldner, Dan Spadoni, and Bill Wells. Special acknowledgement and thanks is given to Toby Owen of the State University of New York at Stonybrook for his expertise as Science Consultant in identifying the scientific rationale and objectives for advanced exploration of Titan.

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INTRODUCTORY STATEMENT OF SCIENTIFIC OBJECTIVES

PRELIMINARY SCIENTIFIC OBJECTIVES FOR ADVANCED TITAN EXPLORATION

by

Tobias Owen, State University of New York at Stonybrook

1. Boundary Conditions

A. Present Knowledge

Our present understanding of the composition of Titan's atmosphere is given in Table 1. There are clearly gradients in the concentration of these species both horizontally and vertically. The aerosol also exhibits such variations, including an obvious equatorial boundary, a polar hood or annulus, and high altitude layering. An average pressure and temperature profile is given as Figure 1. A detailed profile for the lower atmosphere based on the Voyager radio occulation results is reproduced as Figure 2.

B. Key Current Questions - Atmospheric Composition

Among the major constituents of Titan's atmosphere, we still do not know the mixing ratio of methane - its variations with altitude and latitude - or the abundance of primordial argon (^{36}Ar). Better knowledge of the methane mixing ratio is required in order to determine whether or not (and where) methane clouds are forming in the atmosphere, and whether or not there is widespread condensation of methane on the surface of Titan at any latitude. Knowing the abundance of ^{36}Ar in Titan's atmosphere will enable us to determine the extent to which the gases now in the atmosphere were trapped as clathrate hydrates from the primordial solar nebula.

But perhaps the most intriguing questions about Titan's atmosphere concern the minor constituents. It is already apparent from Table 1 that considerable chemical evolution is taking place in this atmosphere. The simple molecules that have already been identified include several of great interest in the synthesis of biomonomers. The presence of both HCN and CO opens pathways toward the formation of nucleotide bases and amino acids. An indication of the chemical complexity that is being achieved is provided by the ubiquitous aerosol. Thus the chemical composition of this smog and the nature of the intermediate compounds are two outstanding questions for future Titan studies. It is now well recognized that this atmosphere offers us a natural laboratory for testing some of our ideas about prebiological chemical synthesis on the primitive Earth. Chemical analysis of the aerosol must be a key component of any future efforts to understand the significance of Titan for studies of the origin of life on Earth.

C. Key Current Questions - The Surface of Titan

We have no direct evidence for the nature of the surface of Titan. The low density of the satellite requires a bulk composition dominated by water ice, suggesting in turn that this material is probably the major component of the surface. By analogy with Callisto and Ganymede, two icy satellites with similar bulk properties, one would expect an absence of large scale, high relief topography because of the plastic flow of the ice over time. The effects of bombardment on Titan's surface will be further mitigated by the presence of the satellite's atmosphere which will act as a shield for the small size range of impacting bodies and will lead to the degradation of larger structures by deposition and erosion. Internal activity on Titan may also play a role in determining surface topography, as it clearly has on the smaller satellites Dione and Rhea.

The continual breakdown of methane with concomitant escape of hydrogen must lead to a gradual accumulation of organic material - the precipitating aerosol - on Titan's surface. The equivalent thickness of this layer has been estimated by Dr. Strobel as approximately 0.5 kilometer. Alternatively, J. Lunine, D. Stevenson, and Y. Yung have suggested that a global ocean of ethane with an average depth of 1 Km could form if ethane is the dominant end product of methane photochemistry. A global methane ocean is ruled out by the radio occultation temperature profile - the methane humidity in the lower atmosphere is too low. But an ethane ocean or high latitude seas and lakes of methane are both possible.

In any event, some source of methane is required to replenish the atmosphere as this gas gets converted to more complex compounds. This source might be episodic venting of gas from the satellite's interior, with methane dissolved in an ethane ocean (or lakes and seas of liquid methane) buffering the system.

To summarize, we don't know the relative proportions of solid and liquid on Titan's surface, the distribution and thickness of organic material deposited from the atmosphere, or the topography and its deteriminants - which could range from bombardment through vulcanism to fluvial erosion.

D. The Next Mission

We expect the next Titan mission to be an atmospheric probe deployed either from a flyby or from a Saturn orbiter. The probe payload will be similar to that of the Galileo probe, but may also include a sophisticated gas chromatograph. We will then know the methane distribution along the descent profile and the abundance of atmospheric argon. We should have more information about gas-phase organic intermediaries between the molecules we know and the smog particles. We will probably obtain very little information on the composition of the smog itself and even less knowledge about the nature of the surface.

This probe could carry a camera capable of sending back a picture of a few square kilometers below the descent trajectory. The flyby (or Saturn orbiter) will be equipped with radar to provide some first-order information about the satellite's surface. This will consist of radar images of varying resolution over some fraction of the total globe. The exact coverage will depend on which type of spacecraft is used to deploy the probe and what trajectories are chosen. The result will not be a comprehensive picture of the surface but may allow detection of some areas where lakes, seas, or oceans of liquid hydrocarbons exist. If there is a global ocean, it may be more difficult to detect by radar. Further study of the general problem of determining surface state and composition by means of radar for these types of materials is required before we will know exactly what can be achieved.

If these spacecraft are also equipped with UV and IR spectromteers, it will be possible to obtain additional information about the global and vertical distribution of atmospheric gases and seasonal effects on the state of the atmosphere (since this mission would undoubtedly take place at a different season from the Voyager encounter). Current ideas about the wavelength dependence of the transparency of Titan's atmosphere suggest that it might be possible to image the surface at wavelengths between 1 and 2 microns, as well as the 17 - 20 micron region. These spacecraft would provide platforms from which such experiments could be attempted. The Space Telescope will provide our first indication of possible atmospheric windows just below one micron.

2. Objectives for a Buoyant Station Mission

It is the thesis of this study that the most important characteristic of Titan is the chemical evolution that has occured and is still occurring in its atmosphere. The production of complex organic compounds from simpler species in a natural environment under the stimulus of electron bombardment and solar ultraviolet light and the subsequent storage of the reaction products on the satellite's surface while hydrogen is free to escape from the planet make Titan unique in the present solar system. The relevance of these processes to the chemistry leading to the origin of life on Earth already seems close enough to make Titan a valuable natural laboratory. Hence it is this aspect of Titan that should receive highest priority for further investigation.

Our current knowledge about Titan and our expectations of what we will learn from he probe mission that we expect to come next have been described in the previous sections. We now need to address those issues that are likely to be unresolved at the time the Buoyant Station Mission (BSM) is undertaken.

The major objective that will still be outstanding is the nature of the organic material that has accumulated on Titan's surface during the last 4.5 billion years. The BSM should be able to make a start toward analyzing this material by providing a survey of its surface distribution along the ground track and by actually sampling some of the material that can be scooped from the solid surface or skimmed from the shores or surfaces of possible ponds of liquid methane.

For the purposes of this study, the BSM is considered to consist of a device analogous to a dirigible that can deploy a payload on a tether up to five kilometers long. Deployment of the Station itself will include the possibility of launching sounding rockets that could sample the aerosol and penetrators that could implant instrumentation in the surface. The Station would be supported by an orbiter that would be instrumented to survey Titan's surface with radar and to study the atmosphere both in the UV and IR.

A. Outstanding Problems After Probe Mission.

Atmospheric Composition

a) The chemical identity of the aerosol. We will have only sketchy information deduced from measurements along the probe trajectory. We must anticipate vertical, temporal, and latitudinal variability in composition of the aerosol material.

b) Preferred pathways for chemical synthesis. Our present understanding of photochemistry and the effects of electron impact will certainly be improved by the probe, but the increased payload and analysis time afforded by the Buoyant Station will allow us to study lower concentrations of gases and hence to determine both end products and intermediates with greater precision.

Atmospheric Structure

a) The hemispheric asymmetry. It seems doubtful that we will know the reason for the different appearance of the northern and southern hemispheres as observed by Voyager without being able to study winds in Titan's lower atmosphere. While some preliminary information should be forthcoming from Doppler tracking of the probe, this will be extremely limited to both time and horizontal distance.

b) Surface winds. Unless an attempt is made to make a survivable probe, we will have no information on winds near the ground.

c) Clouds. The probe will only define clouds along its trajectory. If there is real weather on Titan -- corresponding to phase changes of methane near the surface - the Buoyant Station will be required to define it.

The Nature of the Surface

a) Existence of Liquid Methane. The preliminary radar reconnaisance carried out by the probe carrier should have told us whether widespread areas of liquid methane exist. But detailed radar surveillance will require a Titan orbiter.

b) Extent and Nature of Organic Deposits. We may get some indication of this from the Descent Imager on the Probe - but just in one tiny area of the planet. The Buoyant Station could be equipped to survey its ground track for the presence of organic compounds, to look for layering as well as local deposits formed by horizontal transport and deposition - aeolian or fluvial.

c) Surface Topography and Land-Forming Processes. The Titan Orbiter will be required to locate and identify the Titanian equivalent of volcanoes and streambeds. Detailed surveillance of these areas could then be made by the Buoyant Station. While some craters will undoubtedly be identified by the probe-carrier, the orbiter plus Buoyant Station will be needed to amass the kind of data required for an adequate assessment of Titan's bombardment are erosional history.

The Nature of the Interior

Current models for Titan suggest a rocky core surrounded by a liquid mantle with an icy "lithosphere". This structure could be tested both by the gravitational harmonics measured by the orbiter and by seismometers implanted in the surface.

B. Scientific Objectives: Orbiter

The Orbiter may be launched separately from the Buoyant Station but will certainly be in orbit while the latter is deployed. In addition to its function as support for the station, it can carry out several useful experiments:

1) Radar Mapping of Surface: Suggest using VRM as a model. The resolution would be between 0.5 to 1 Km over the entire surface. We would then know the characteristics of Titan's surface at the same scale we know the surface of Mars and Venus.

2) Spectroscopic Observations: Both UV and IR spectroscopy should be pursued. Besides the additional seasonal information this effort would provide, some specific problems could be approached that would not have been solved by previous missions. These might include efforts to map the surface at 17 to 20 microns and to explore the IR spectrum beyond 50 microns, where we may well have no data. This wavelength range is important because it will provide much better definition of the thermal radiation emitted by Titan's surface and lower atmosphere, besides allowing searches for additional molecular species in emission. A better picture of the thermal balance of the atmosphere should emerge.

3) Radio Experiments: Repeated radio occultations will permit definition of temperature profiles at a variety of latitudes. Doppler tracking of the station and sounding balloons will permit studies of local winds.

4) Imaging. By the time the BSM is deployed, we should know whether or not the atmosphere of Titan is transparent in the 1 to 2 micron region. If it is, it should be possible to build up an IR image of the surface with an imaging system that might be a line-scanning device (technology will surely be much more advanced in this area).

5) Gravity. Studying the orbit of the orbiter should allow determination of gravitational harmonics that will help define the internal structure of Titan.

6) Particles and Fields. Voyager showed that Titan is occassionally completely outside Saturn's magnetosphere. Hence a spacecraft in orbit about the satellite provides a useful station from which to study the boundary phenomena as well as conditions deep within the magnetosphere.

7) Particulates. An important question remaining from the Voyager studies is the amount of icy material presently entering Titan's atmosphere, presumably in the form of ice grains. The orbiter could be equipped with a particle impact detector that could measure this flux. With a little more sophistication, this same instrument - or an add-on - could do rudimentary compositional analysis, e.g., to determine the mass fraction of ice in individual particles.

C. Scientific Objectives - Sounding Rocket or Alternative Haze Probe

As the Buoyant Station is deployed, a sounding rocket could be released from the heat shield during entry. This rocket could have an apogee of 250 Km, which would take it into the lower part of the upper haze layer. An alternative approach would be a specialized entry probe reaching Mach 1 at high altitude. Its principal function would be an analysis of the aerosol particles and the gaseous constituents in the region between 250 to 100 Km. The atmospheric probe mission that precedes the BSM will begin operations at 100 Km. Hence this outer skin of the satellite's atmosphere - where most of the chemistry is probably happening - will not have been sampled prior to this mission.

1) Gases. The instrument of choice is some form of Gas Chromatograph-Mass Spectrometer. It may prove more desirable to have two separate instruments. It is important to maximize sensitivity, to reach concentrations of less than 1 ppb, while retaining the ability for unambiguous identification of the detected species.

2) Aerosol. At present we do not have an adequate flight instrument for analyzing the aerosol. There are two steps: a) capturing the particulates and b) determining their chemical composition. There is now considerable experience with step a); the trick is to coordinate it with step b). The method commonly suggested for this step is liquid chromatography. A design study must be done to see whether a flight instrument is practical. The fall back approach would be the use of mild pryolysis to vaporize the sample for subsequent analysis with the GCMS.

3) Atmospheric Structure. While the rocket is performing its main function, it could also be measuring local T and P during its (parachute-assisted) descent.

D. Scientific Objectives: Buoyant Station

Surface Surveillance. A radar altimeter will probably be necessary to provide constant monitoring of the station's altitude. If this device includes several wavelengths, it could also provide some information on the nature of the surface. A IR Camera should be able to provide images of the surface, given the light levels predicted by current models. We will obviously know the illumination much better after the probe mission. An IR spectrometer could be used as a survey instrument to identify compositional differences on the satellites's surface. It might prove most practical to combine this function with the camera and simply have an IR imaging device that would use filters to isolate wavelength regions of special interest. Note that you could even carry a source of illumination, if necessary.

Weather. The station should be equipped to monitor temperature, pressure, wind speed, upward and downward flux, horizonal transmission of light (nephelometer), and relative humidity (of methane!). The flux measurements should include thermal IR from surface and the full range from 2000 Å to 5 microns of incident solar flux. These various flux measurements should allow the detection of clouds. Further information would be forthcoming from the deployment of sounding balloons, that could also be tracked by the orbiter to provide additional information on wind speed and T, P profiles.

General Circulation. This obviously overlaps with weather. But the key objective here would be to determine the reason(s) for the difference in the aerosol layer between the northern and southern hemispheres that seems clearly defined by the satellite's equator. A possible strategy for attacking this problem would be the deployment of the station in such a way that it could cross the equator as part of its traverse, possibly releasing sounding balloons on either side.

Surface Chemistry. The station will have to be equipped with a scoop that can sample relatively loose material on the surface. This could be organic matter originally deposited as precipitating aerosol and subsequently concentrated by aeolian or fluvial processes or else organic material floating as scum on ponds of methane - or collected at the shores of such ponds. Once the material is retrieved, liquid chromatography and/or mild pyrolysis followed by GCMS would seem to be the appropriate analytical tools. Note that we should expect exogenous organic material as well as indigenous material. Because of its thick, reducing atmosphere and low temperature surface, Titan is an excellent repository for meteoritic and cometary debris.

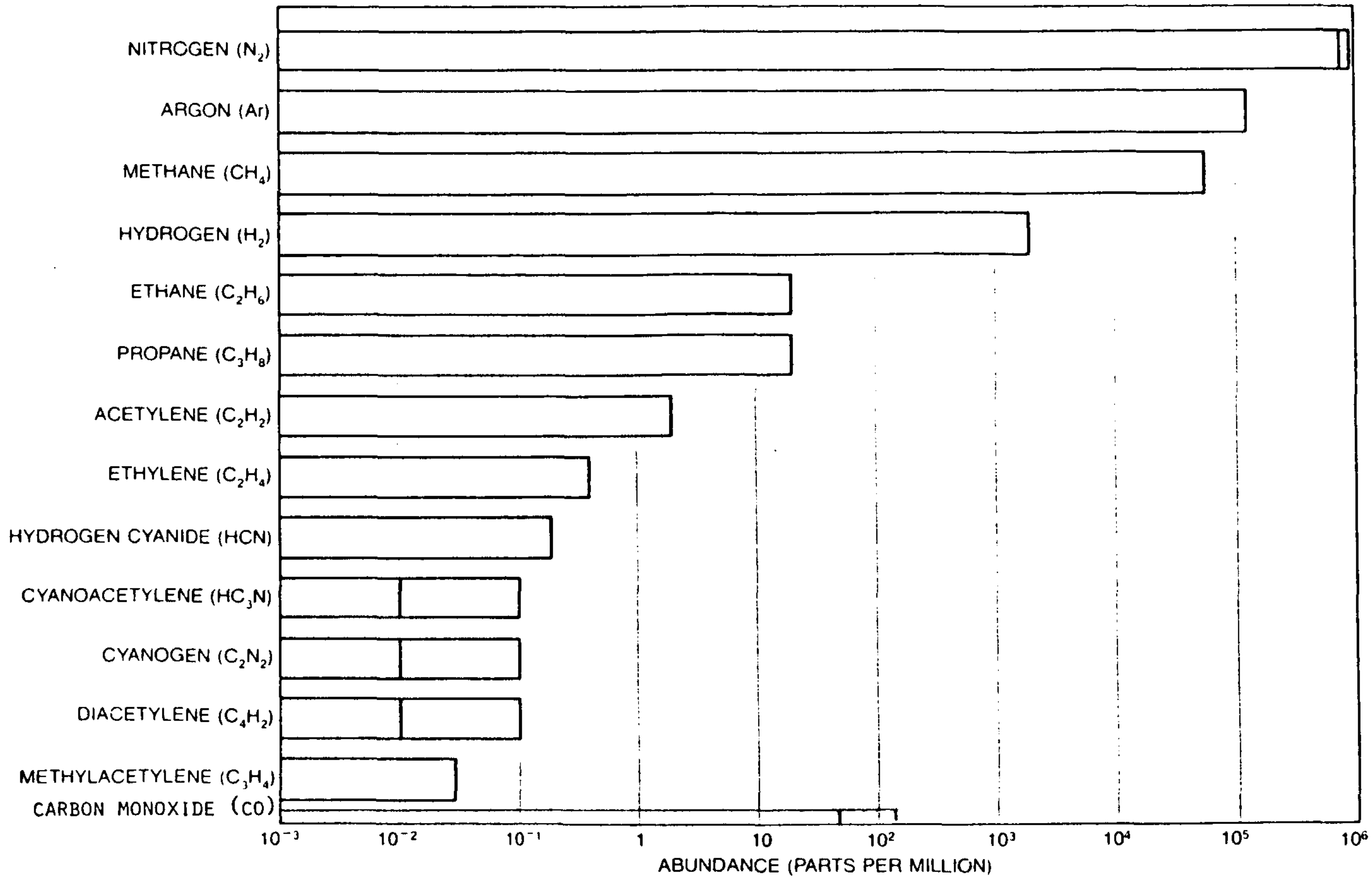
Surface State. The surveillance instrumentation described above will give a good idea about relative amounts and locations of liquids, solids, and movable debris (sediment). Further analysis might take the form of deployably sonar buoys, that could determine the depths of any lakes or seas that are present, and might also be able to detect layers of organic material floating below the surface. Simple weather stations could also be deployed as floating buoys, maintaining contact with the orbiter. Maintaining thermal barriers in this low temperature environment may be the most serious obstacle.

E. Scientific Objectives: Penetrators.

Surface Weather. A network of penetrators could provide simple weather stations at a variety of locations on the satellite.

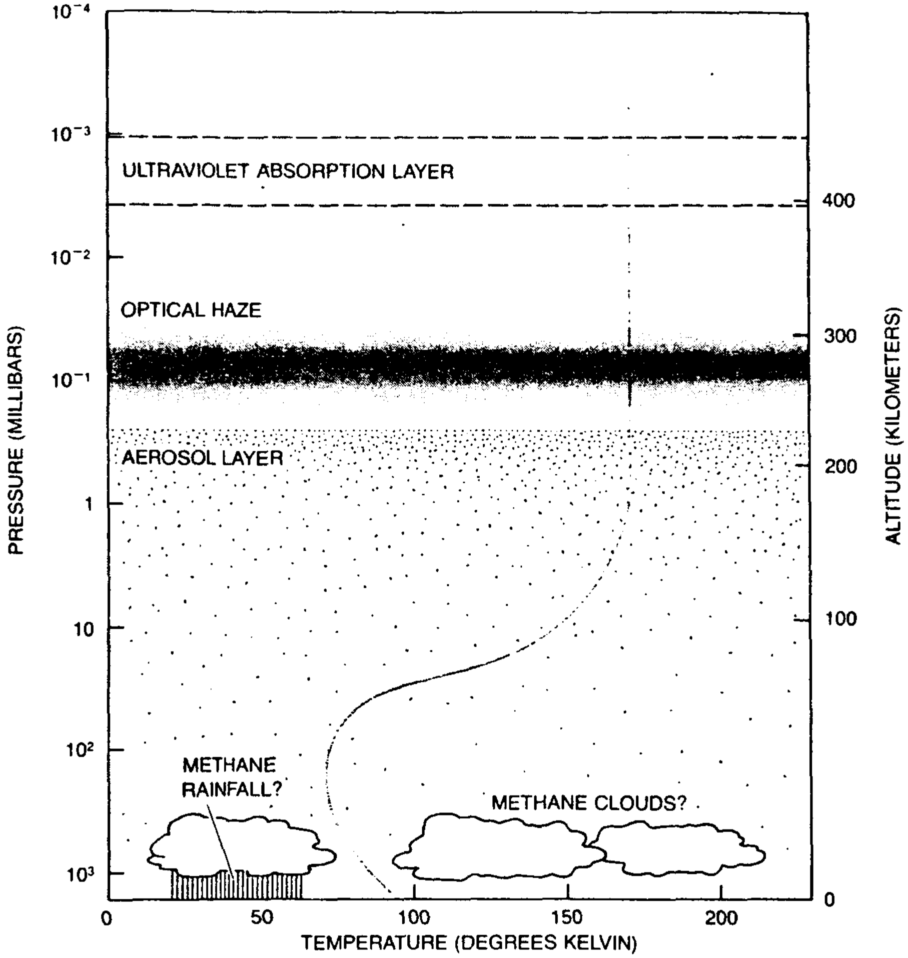
Internal Structure. Seismometers deployed by penetrators should be capable of monitoring ice movement. Setting off a charge - or arranging a suitable impact - might allow one to determine the thickness of the lithosphere by looking for the absense of S waves transmitted through the liquid mantle.

Chemical Analysis. Penetrators offer the easiest way of sampling subsurface material. A device with a heated, detachable nose cone could reach a considerable depth, based on studies done for the deployment of penetrators on the Martian polar cap. A rudimentary analysis of pyrolized subsurface material should be able to identify layering of organics and thus provide some initial clues about the recent history of the surface. It would be especially interesting to look for evidence of sulfur and phosphorous in these earlier deposits, since both of these volatiles are apparently now missing from the atmosphere.



GASES IN TITAN'S ATMOSPHERE are now thought to vary in abundance from molecular nitrogen (set at 82 to 94 percent of the atmosphere, or 820,000 to 940,000 parts per million, as a result of Voyager data) to trace quantities of hydrocarbons such as methylacetylene and nitrogenous substances such as cyanogen. Several further trace constituents of Titan's atmosphere may remain to be discovered. The chart indicates some 12 percent (120,000 parts per million) of the inert gas argon. This 12 percent is required to raise the mean molecular weight of the gases that make up Titan's atmosphere to the value of 28.6 that tentatively emerges from the Voyager data.

Table 1 (from Scientific American, Feb. 1982)



CROSS SECTION OF TITAN'S ATMOSPHERE includes two layers whose presence was discovered by *Voyager 1*. They are a layer transparent to visible light in which ultraviolet radiation is absorbed and below it the layer of high-altitude haze. Below the haze lies the layer of aerosol particles. It is presumed that the particles have been aggregating into larger particles and falling to the surface over the history of the solar system. Methane clouds and methane rainfall are shown above the surface; they are unconfirmed but likely. The curve showing temperature v. pressure (*color*) is based on an experiment in which the atmosphere of Titan intervened between the earth and the radio signals transmitted by *Voyager 1*. According to the data amassed by means of this occultation (along with Voyager data from infrared spectroscopy), the surface temperature on Titan is about 95 degrees Kelvin and the surface pressure is 1,500 millibars (1.5 bars). The average sea-level pressure on the earth is slightly more than one bar.

Figure 1 (from Scientific American, Feb. 1982)

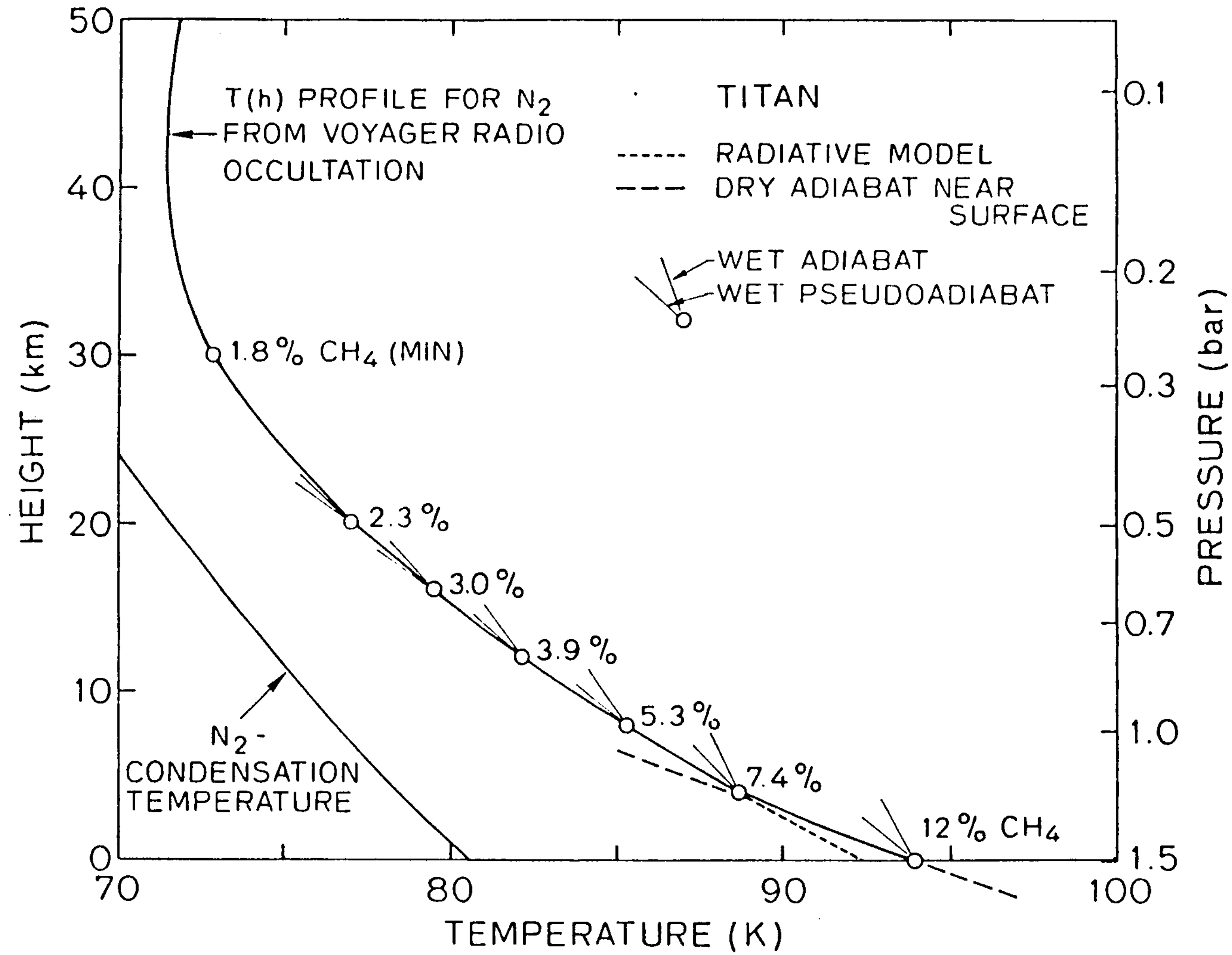


Figure 2 (from Eshleman, et al)

EXECUTIVE SUMMARY

STUDY RATIONALE

TITAN EXPLORATION WITH ADVANCED SYSTEMS

- MISSION RATIONALE
  - INTRIGUING AND UNIQUE BODY IN SOLAR SYSTEM
  - EXPLORATORY LEVEL SCIENCE BEYOND VOYAGER, TITAN PROBE AND SATURN ORBITER RADAR MAP
  - APPROPRIATE IMPLEMENTATION AROUND TURN OF CENTURY

- STUDY RATIONALE
  - POTENTIAL AUGMENTATION TO SSEC CORE PROGRAM
  - STUDY RESULTS TO BE PRESENTED AT SSEC SUMMER STUDY

- STUDY OBJECTIVES
  - PRELIMINARY STUDY IDENTIFYING RELEVANT SCIENCE OBJECTIVES, MISSION CONCEPTS, DESIGN REQUIREMENTS AND PROGRAMMATIC ISSUES
  - FAVORED MISSION CONCEPT IS BUOYANT STATION(S) SUPPORTED BY TITAN ORBITER
    1) CAPABLE OF EXPLORING ATMOSPHERE AND SURFACE, IN SITU & REMOTE SENSING
    2) ADAPTIVE TO SEVERAL POSSIBLE SURFACE PHYSICAL STATES AND TOPOGRAPHIES
    3) REGIONAL AND POSSIBLY GLOBAL MOBILITY OF SCIENCE PAYLOAD

SCIENTIFIC OBJECTIVES

SCIENCE OBJECTIVES AND MEASUREMENT TECHNIQUES - TITAN MISSION

OBJECTIVE	ATMOSPHERIC/SURFACE TECHNIQUE	ORBITAL TECHNIQUE
UPPER ATMOSPHERIC CHEMISTRY AND HIGH ALTITUDE HAZE	GAS CHROMATOGRAPHY MASS SPECTROMETRY NEPHELOMETRY	PLASMA ANALYSIS MASS SPECTROMETRY UV SPECTROSCOPY
LOWER ATMOSPHERE COMPOSITION, INCLUDING PRECIPITATION AND CLOUDS	GAS CHROMATOGRAPHY MASS SPECTROSCOPY IR SPECTROSCOPY NEPHELOMETRY	IR SPECTROSCOPY
ATMOSPHERIC STRUCTURE AND GLOBAL CIRCULATION	TRACKING RADAR ALTIMETRY IR SPECTROSCOPY PRESSURE, DENSITY, TEMP.	OCCULTATION IR SPECTROSCOPY NEAR IR IMAGING
SURFACE COMPOSITION	IR SPECTROSCOPY SAMPLE COLLECTION FOR GC, MS ELEMENTAL COMPOSITION	—
SURFACE FEATURES AND MORPHOLOGY	NEAR IR IMAGING RADAR ALTIMETRY SONAR	RADAR IMAGING NEAR IR IMAGING
INTERIOR STRUCTURE	SEISMOMETRY	TRACKING

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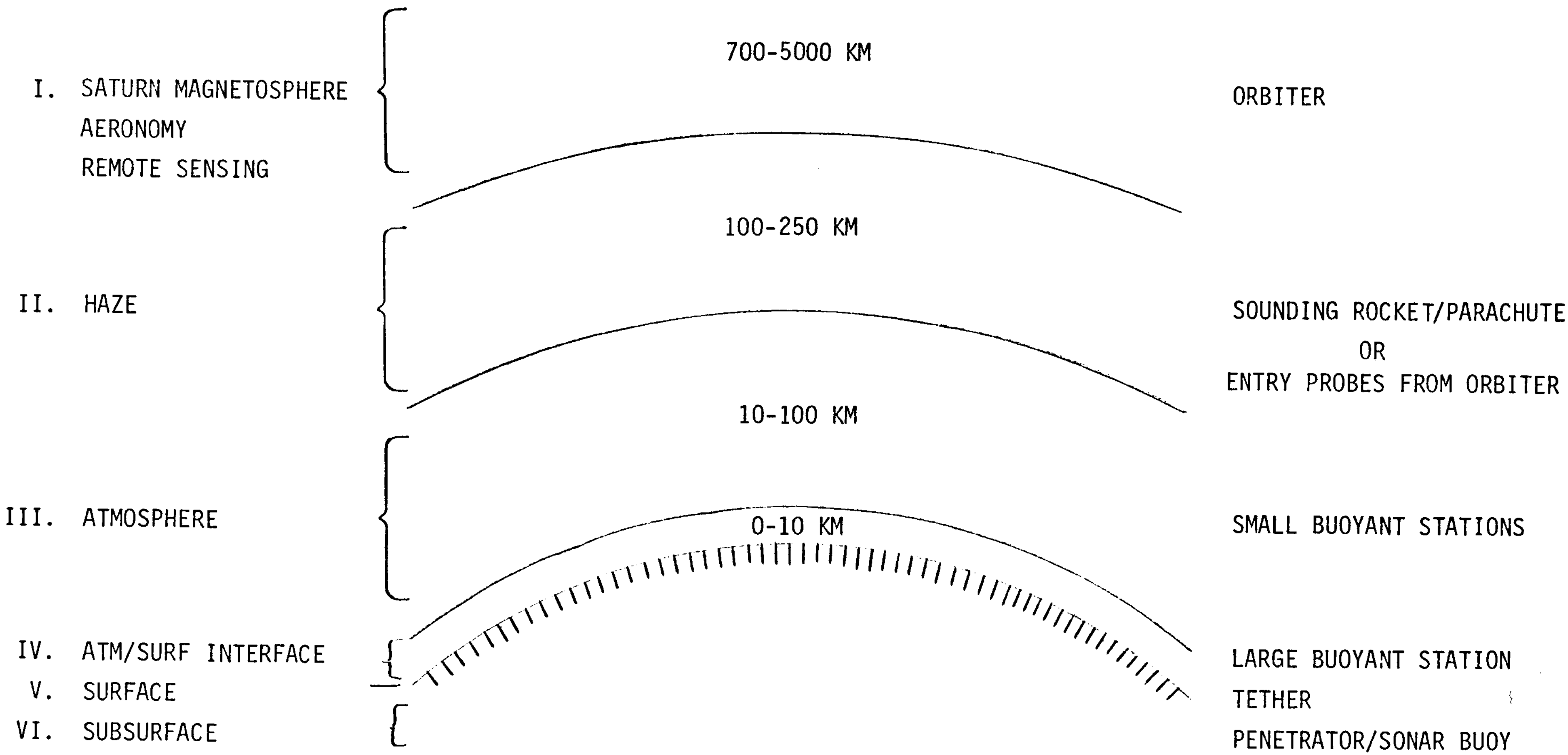

CLASSES AND METHODS OF TITAN SCIENCE INVESTIGATION

CANDIDATE SCIENCE PAYLOADS

The scientific objectives and measurement techniques discussed in the Introductory Statement and summarized by the preceding charts provided the basis for selection of candidate payloads. Another factor of consideration was a study-imposed guideline to examine a range of possible options for configuring a Titan-intensive mission. Finally, preliminary results of trajectory analysis and mass delivery performance calculations offered some judgement as to supportable limits on science payload mass. Estimates of instrument mass, power and data were taken from existing or proposed designs when appropriate, or anticipation of new science developments within the next decade.

The table on the facing page and the next two pages list the candidate payload selections for a Titan orbiter, buoyant station, haze probe, and penetrator. Two orbiter options are presented: (1) a non-imaging payload comprised of particle & field instruments and remote sensing experiments in the UV and IR spectrum; and (2) the addition of radar and near-IR experiments to define an imaging orbiter. Total payload mass estimates are 55 kg and 125 kg, respectively.

The buoyant station payloads were also separated into two classes. For (small) sounding balloons operating in the troposphere, a payload of 20 kg includes a miniaturized GC (new development), four experiments of Galileo probe heritage, and some form of aerosol sample collector (new development). For the (large) balloon or blimp operating close to the surface, a more capable GC/mass spectrometer is substituted in the above payload, and a radar altimeter near IR imager, IR spectrometer, and some form of surface sample collector are added bringing the total science payload to 80 kg. For a liquid surface state, the surface package would include a sonar sounding experiment.

The candidate science payload for a haze probe weighs 16 kg and consists of a miniaturized gas chromatograph, mass spectrometer, atmospheric structure, and aerosol sample collector. A combined haze/penetrator probe is also defined in which case the mass spectrometer and aerosol experiment has a physical separation interface with the remaining instruments located on the penetrator. The gas chromatograph and atmospheric structure instruments are located on the penetrator afterbody but operate during descent through the haze layer. The penetrator forebody includes an elemental composition experiment, seismometer, and accelerometer. Total payload mass for the combined haze/penetrator probe is 20 kg.

CANDIDATE SCIENCE PAYLOADS - TITAN ORBITER

INSTRUMENT	MASS(KG)	POWER(W)	DATA RATE(B/S)	COMMENT
• NON-IMAGING ORBITER				
MAGNETOMETER	5	6	10	SATURN MAGNETOSPHERE/SOLAR WIND
PLASMA WAVE	4	3	200	SATURN MAGNETOSPHERE/SOLAR WIND
PLASMA ANALYZER	4	8	20	LOW ORBIT AERONOMY
NEUTRAL MASS SPECTROMETER	5	8	10	LOW ORBIT AERONOMY
DUST PARTICLE ANALYZER	20	(20)	10	ICE GRAIN COMPOSITION, DENSITY
OCCULATION, TRACKING	-	-	-	TEMP PROFILE, GRAVITY FIELD
UV SPECTROMETER	5	5	100	GLOBAL SOUNDING
THERMAL IR SPECTROMETER	12	10	100	GLOBAL SOUNDING
TOTAL......................	55	40	450	
• IMAGING ORBITER				
ALL OF ABOVE	55	40	450	
NEAR IR IMAGER	20	25	5,000	2 μm, 1 KM RESOLUTION
RADAR IMAGER	50	50	5,000	SCALED DOWN VRM, 1 KM
TOTAL....................	125	115	10,450	

( ) = INFREQUENT USE OF POWER

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CANDIDATE SCIENCE PAYLOADS - BUOYANT STATION

INSTRUMENT	MASS(KG)	POWER(W)	DATA RATE(B/S)	COMMENT
• SMALL BALLOON				
GAS CHROMATOGRAPH	2	9	20	MINIATURIZED AMES DESIGN
ATMOSPHERIC STRUCTURE	4	6	20	GALILEO HERITAGE
LIGHTNING DETECTOR	1	1	10	GALILEO HERITAGE
TRACKING	—	—	—	FROM ORBITER
NET FLUX RADIOMETER	3	7	20	GALILEO HERITAGE
NEPHELOMETER	4	13	10	GALILEO HERITAGE
AEROSOL SAMPLE COLLECTOR	6	(10)	—	PYROLYSIS → GC OR LIQUID CHROMATOGRAPHY
TOTAL	20	36	80	
• LARGE BALLOON OR BLIMP				
ALL OF ABOVE EXCEPT GC	18	25	60	
GC/MASS SPECTROMETER	15	40	100	SENSITIVITY 1 ppb OR BETTER
RADAR ALTIMETER	10	15	10	RANGING, POSSIBLY MORE
NEAR IR IMAGER	10	10	1,000 (XMIT)	2 μm, 2 x 10^6 BITS/PICTURE
IR SPECTROMETER	12	10	30	SURFACE COMPOSITION SURVEY
SURFACE SAMPLE COLLECTOR	15	(25)	—	ON SURFACE PACKAGE (WITH GC/MS?)
TOTAL	80	100	1,200	

( ) = INFREQUENT USE OF POWER

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CANDIDATE SCIENCE PAYLOADS - HAZE/PENETRATOR PROBES DEPLOYED FROM ORBITER

INSTRUMENT	MASS(KG)	POWER(W)	DATA RATE(B/S)
• HAZE ONLY			
GAS CHROMATOGRAPH	2	9	20
MASS SPECTROMETER	4	13	6
ATMOSPHERIC STRUCTURE	4	6	20
AEROSOL SAMPLE COLLECTOR	6	(10)	—
	16	28	46
• HAZE/PENETRATOR			
MASS SPECTROMETER	4	13	6
AEROSOL SAMPLE COLLECTOR	6	(10)	—
GAS CHROMATOGRAPH	2	9	20
ATMOSPHERIC STRUCTURE	4	6	20
ELEMENTAL COMPOSITION	2	4	20
SEISMOMETER/ACCELEROMETER	2	4	20
	20	36	86

( ) = INFREQUENT USE OF POWER

MISSION CONCEPTS

ELEMENTS AND OPTIONS FOR TITAN MISSION DEFINITION

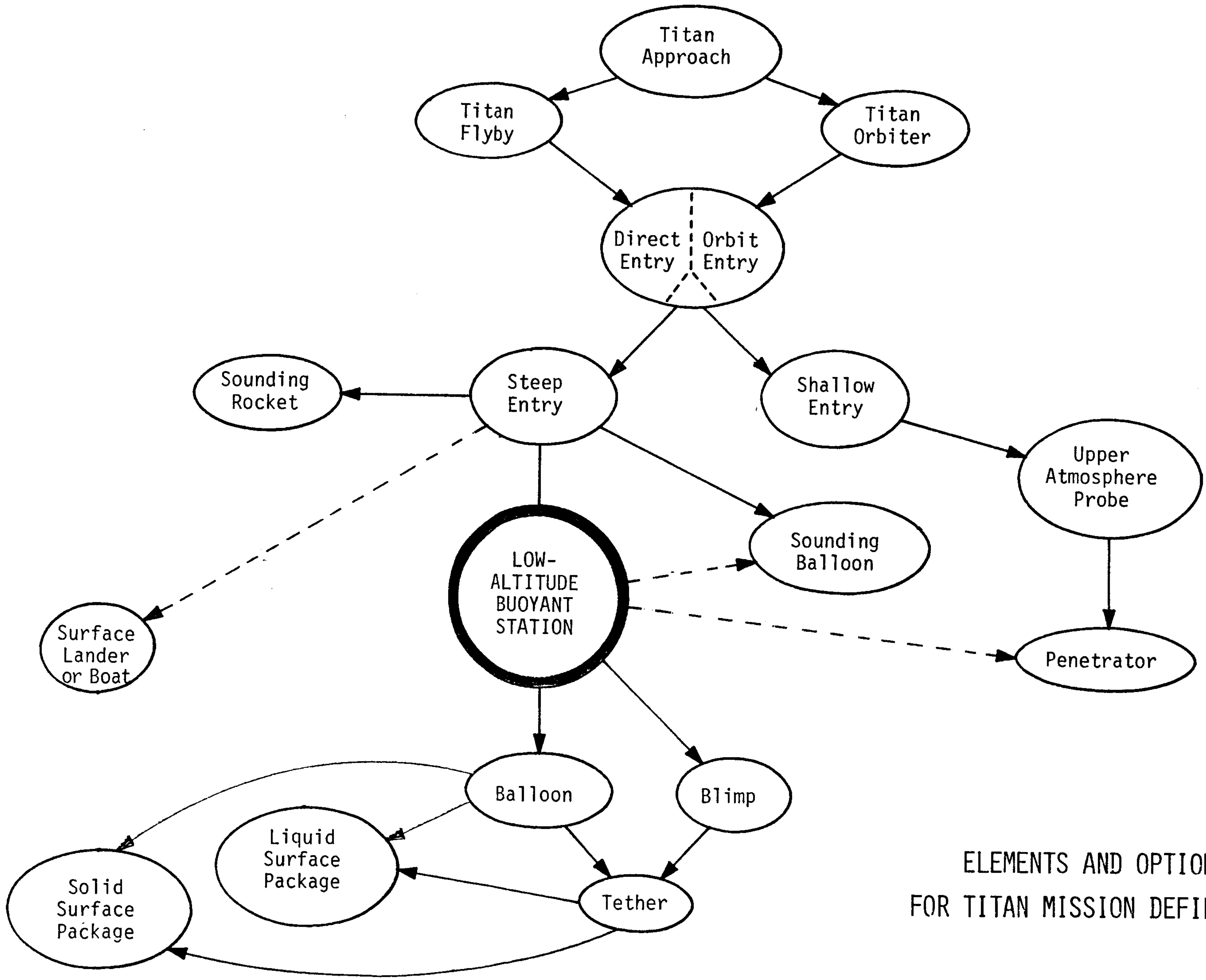
The facing page illustration depicts various building blocks for configuring an advanced Titan exploration mission. Such a mission is centered about one or more balloon vehicles operating in the Titan atmosphere and supported by a spacecraft in orbit about Titan. Other exploration elements operating in or descending through the atmosphere are also considered, e.g. a high altitude haze probe or sounding rocket, an instrumented package lowered or dropped to the surface, and a subsurface penetrator.

Two options for deploying atmospheric devices are from the Titan orbiter or from a separate probe carrier on flyby approach to Titan. In general, out-of-orbit entry involves shallow entry path angles of the order 5° to 10° whereas flyby deployment involves steeper entry angles of 30° to 90°. Standard entry probe designs like Galileo are most appropriate for conveying the larger mass and volume equipment needed for balloon/buoyant station deployment in the mid-to-low altitude regions of the atmosphere. For upper altitude haze measurements via entry probe, a more suitable design is a deployable fabric decelerator having a large drag area (low ballistic coefficient) entering the atmosphere at shallow angles. This type of design also lends itself to deployment of long, slender penetrator configurations so that one may consider a combined haze/penetrator probe.

The option paths represented by broken lines were given some thought but generally discounted for reasons of operational complexity or design difficulty. These include deployment of sounding balloons or penetrators from the low altitude buoyant station. A large surface lander or boat (Viking-class) was also omitted from the present study, although it is recognized that either concept might be well-suited to advanced exploration of Titan if the surface state were well defined in advance.

The low altitude buoyant station is optionally configured as a balloon or a blimp (airship). An airship under propulsive power is clearly more flexible in operational mobility and control of a tethered surface package -- it's design is also more complex. An option for the balloon station without a tether is to drop one, or at most a few, experimental packages to the surface but without retrieval capability.

Several mission concepts will be defined from the hardware element options illustrated. The goal in this selection is to encompass a range of exploration capability (and presumably cost) which might be considered for future missions to Titan.



ELEMENTS AND OPTIONS
FOR TITAN MISSION DEFINITION

GROUNDRULES FOR MIX 'N' MATCH MISSION CONCEPTS

The various options for hardware elements and deployment modes that have been described may be combined in numerous ways to define a total mission concept. For purposes of this preliminary study, it is deemed inappropriate to define a single baseline mission concept. Rather, we wish to examine a range of possibilities in some detail and present these for consideration. The limited set of reference concepts selected should encompass an exploration level from some reasonable minimum to maximum science capability; the associated mission costs would presumably follow the level of complexity and capability specified. One may reasonably expect that other potential concepts viewed as "variations on the main theme" would have costs lying somewhere within this range.

The guidelines stated on the facing page chart were used in the selection of five reference mission concepts. The first two guidelines represent minimal requirements for atmosphere and surface science. A key requirement for all concepts is the presence of an orbiting spacecraft to perform continuous remote sensing experiments in the near vicinity of Titan and which is virtually a necessity to support the in situ atmosphere/surface operations. The last guideline is imposed so as not to overburden the orbiter vehicle.

GROUNDRULES FOR MIX 'N' MATCH MISSION CONCEPTS

- ALWAYS HAVE AT LEAST ONE IN SITU ATMOSPHERIC HARDWARE ELEMENT
- ALWAYS HAVE SOME FORM OF SURFACE SCIENCE
- ALWAYS HAVE A TITAN ORBITER
- ORBITER DOES NOT CARRY BOTH LAUNCH TUBE DEPLOYED DEVICES AND STANDARD ENTRY PROBES

SELECTED MISSION CONCEPTS

Five reference mission concepts are described in terms of the hardware elements comprising these missions. Concept 1 represents a minimum level of capability; note that it does not include any balloon or buoyant station elements. A single launch delivers a non-imaging orbiter from which are deployed several (nominally 3) haze/penetrator probes. The use of penetrators assumes a solid surface state, at least in some regions of the planet. Concepts 2 through 4 all employ dual launches with separate delivery of orbiter systems and balloon/buoyant station systems. The balloons are packaged in standard entry probes delivered to Titan by a flyby probe carrier which otherwise has no science function. Concept 2 includes an imaging orbiter, 3 haze/penetrator probes, and 3 sounding balloons operating in the troposphere at altitudes up to about 70 km. Concept 3 specifies an imaging orbiter without orbiter-deployed probes; the flyby probe carrier delivers 3 sounding balloons and a large balloon station operating in the lower atmosphere carrying one or more small science packages dropped to the surface. Haze science is accomplished in this case by a sounding rocket packaged in the large balloon entry probe and launched upward at about 100 km altitude. Concept 4 represents the upper bound on mission complexity and science capability. Haze probes are deployed from the imaging orbiter, and the flyby probe carrier delivers sounding balloons and a low-altitude buoyant station (blimp type) with a tethered surface package appropriate to either solid or liquid surface states -- or possibly both. Concept 5 represents an example of a multi-element delivery with a single launch. It includes a non-imaging orbiter, sounding balloons, and a low-altitude buoyant station (blimp type) with a tethered surface package. In situ haze science is not included. The balloons and buoyant station are deployed from Titan orbit and packaged in four standard entry probes. The large mass/-volume requirement implied by this last mission concept can probably be satisfied only by nuclear electric propulsion delivery.

TITAN ATMOSPHERE AND SURFACE INVESTIGATION - MISSION CONCEPTS

CONCEPTS	FLYBY PROBE CARRIER	TITAN ORBITER		UPPER ATMOSPHERE HAZE		ATMOSPHERE				SURFACE (LIQUID OR SOLID)		SUB-SURFACE (METERS)	
						TROPOSPHERE		LOWER					
		W/O RADAR & IR IMAGER	W/ RADAR & IR IMAGER	SOUNDING ROCKET	ENTRY PROBE	DESCENT PROBE MEAS.	SOUNDING BALLOON	BUOYANT STATION (BALLOON)	BUOYANT STATION (BLIMP)	TETHERED PACKAGE	DROPPED PACKAGE	TETHER (LIQUID)	PENE-TRATOR (SOLID)
1		X			X --	-- >							X
2	(X)		X		X --	-- >	(X)						X
3	(X)		X	(X)			(X)	(X)			(X)		
4	(X)		X		X --	-- >	(X)		(X)	(X)		(X)	
5		X					X		X	X		X	

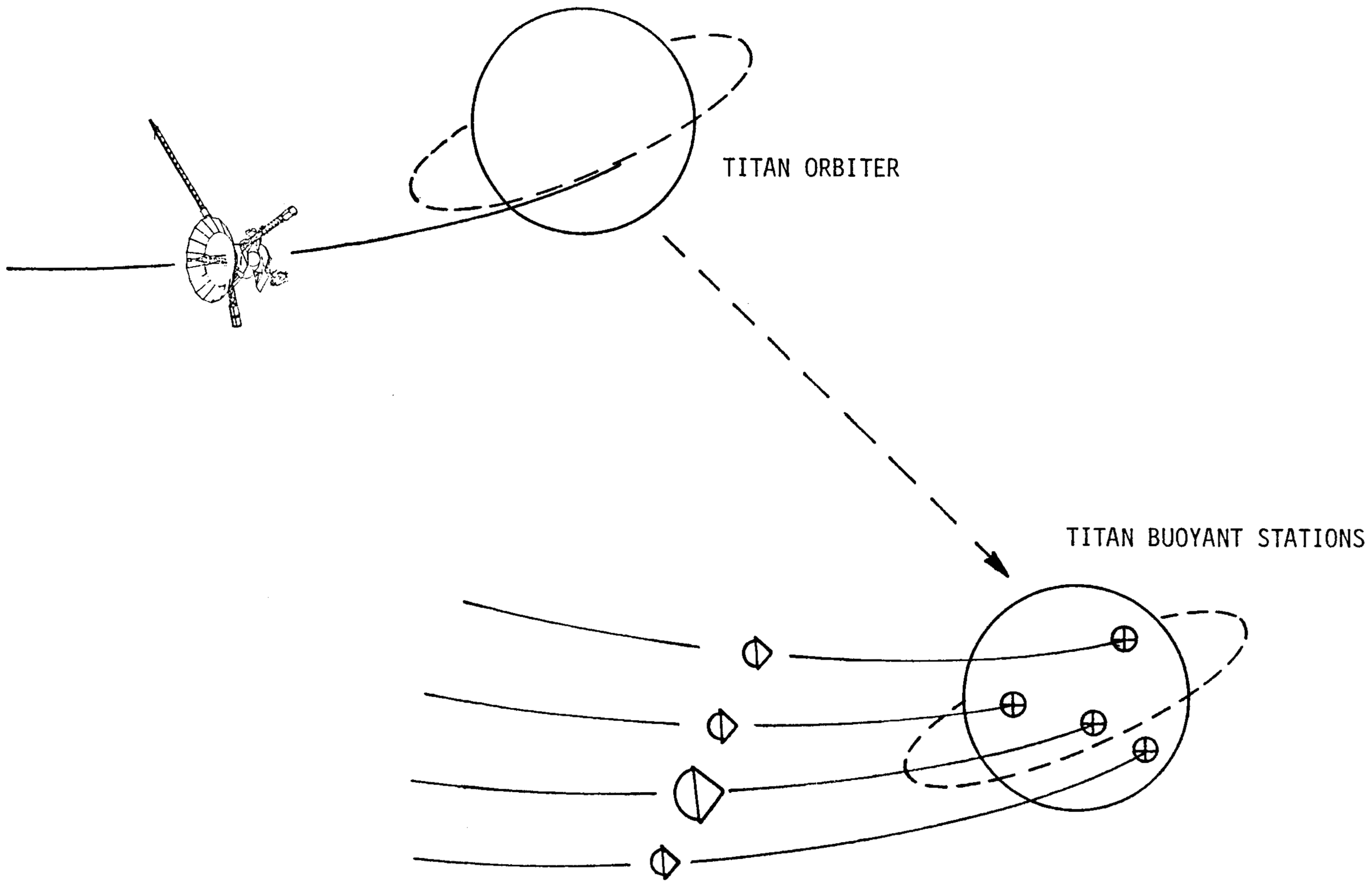
X ORBITER-DEPLOYED SPACECRAFT ELEMENTS

(X) FLYBY PROBE CARRIER-DEPLOYED SPACECRAFT ELEMENTS

A POSSIBLE MISSION SCENARIO FASHIONED AFTER PIONEER VENUS

Although two separate launches are required, this is a viable mission implementation mode for delivery of the relatively large mass hardware elements required for advanced Titan exploration. The Titan orbiter vehicle is launched first and performs much of its remote sensing function prior to arrival of the buoyant station probes. The orbiter may also deploy atmospheric entry devices such as the specialized haze or haze/penetrator probes. Launched second, perhaps a year later, the probe carrier delivers as many as four standard entry probes in which are packaged the buoyant stations. These probes are released on approach to Titan flyby and targeted to selected longitude/latitude locations. They arrive at least six months after orbiter emplacement. Accurate targeting without on-board optical navigation is made possible by the orbiting spacecraft serving as a radio beacon and determinant of the ephemeris of Titan's orbit about Saturn. After buoyant station deployment, the orbiter's primary function is to serve as a communications relay link between the operating stations and data return to Earth. The orbiter can also perform complementary remote sensing experiments during this time and, if appropriate, may contine its science mission (e.g. aeronomy) after completion of the buoyant station mission.

A POSSIBLE MISSION SCENARIO FASHIONED AFTER PIONEER VENUS

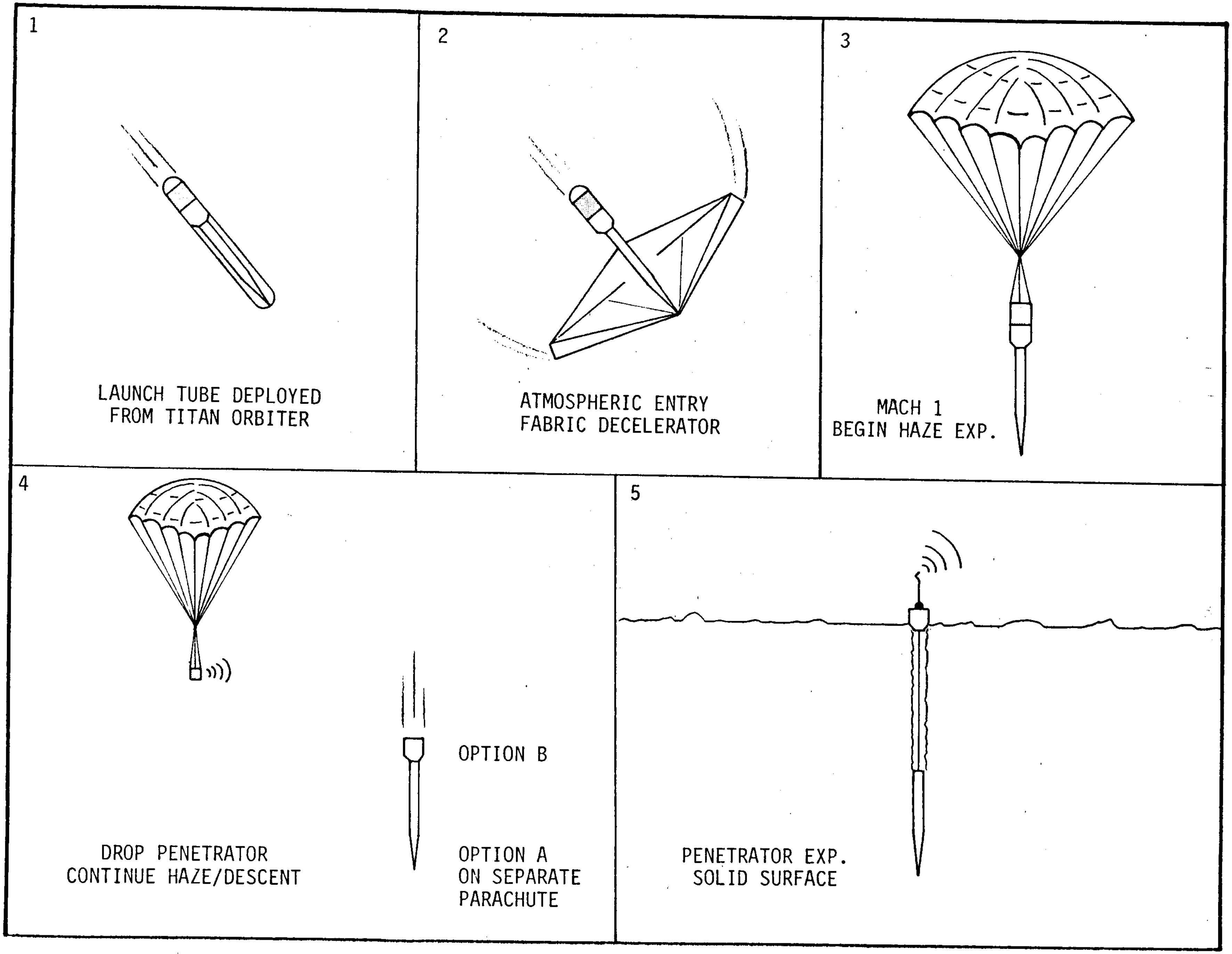


HAZE/PENETRATOR PROBE DEPLOYMENT SEQUENCE

The proposed Mars penetrator system serves as the design base for this mission concept. The combined haze/penetrator is packaged in a cylindrical tube and launched from the orbiter using a small solid propellant motor. De-orbit ΔV requirement is about 70 m/sec; because of the high thrust acceleration of the solid motor, this terminal speed is reached before the cylinder exits the launch tube -- hence, pointing control is entirely under the direction of the orbiting spacecraft. A deployable fabric decelerator provides a low ballistic coeffient of 10 kg/m^2 during atmospheric entry (5° entry angle) thus allowing Mach 1 speed to be reached at about 265 km altitude. The orbiter is 4.5° behind the probe at this time. After the decelerator is jettisoned, a parachute is deployed to slow the descent through the haze layer. The experiment time from Mach 1 down to 150 km is 17 minutes; the orbiter is directly overhead at about 4 minutes (probe at 225 km altitude) and then begins to lead the haze probe at an increasing rate going over the horizon at 23 minutes after experiment initiation when the probe is at 100 km altitude.

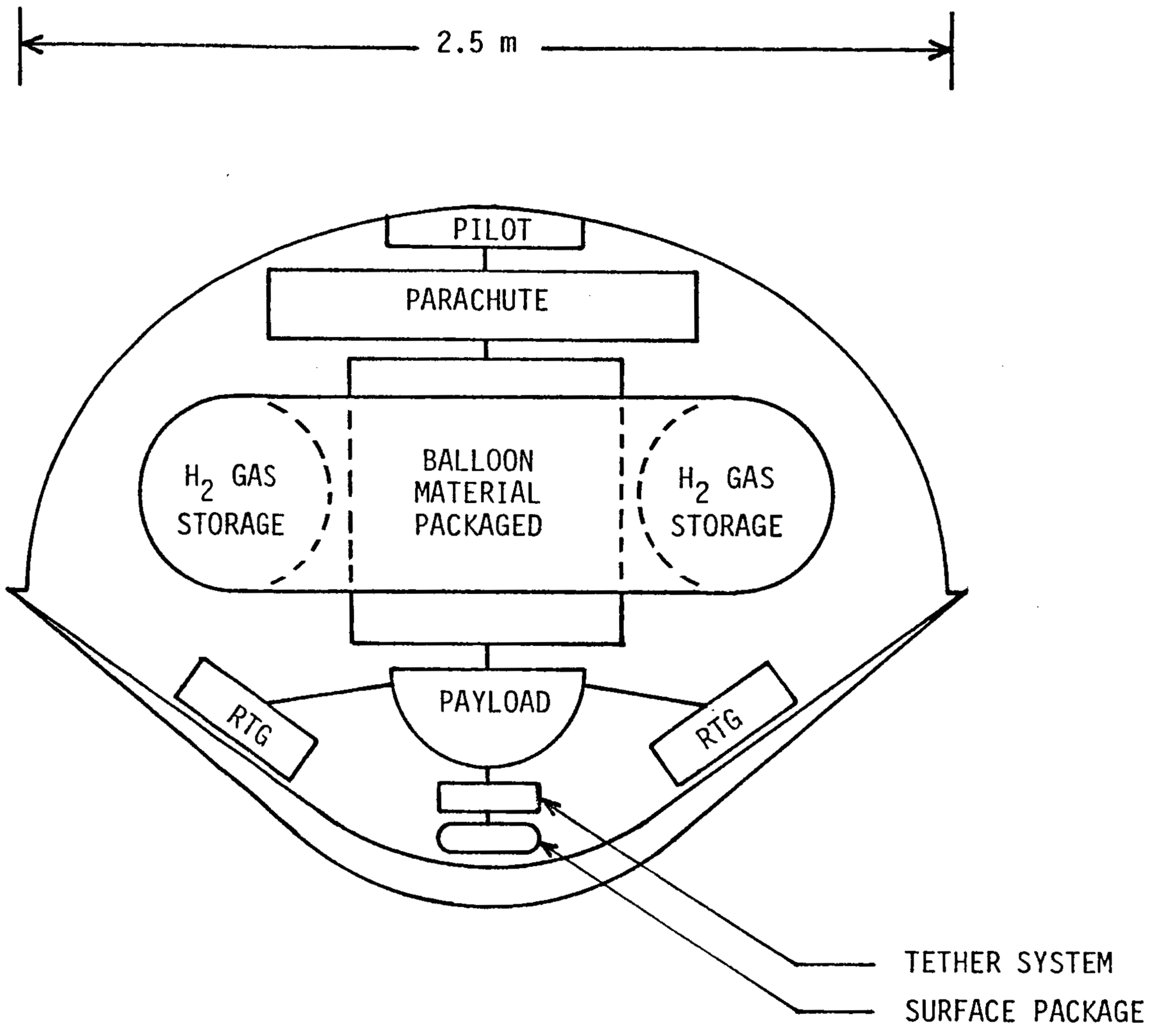
Meanwhile, the penetrator is jettisoned to continue a faster descent to the surface. Two options are possible: (a) early release on a separate parachute when the probe altitude is about 190 km with parachute jettison 10 minutes later; or (b) later release without parachute when the haze probe reaches 145 km. In either case, the penetrator impacts the surface at 70 m/sec several minutes before communications visibility with the orbiter is lost. Assuming a cross-dipole antenna pattern for the penetrator transmitter, the large off-zenith angle will probably necessitate signal reception at the orbiter by a directed parabolic antenna. The limited time available after impact will only allow the accelerometer data and other preliminary science information to be transmitted on this first pass. Accumulated stored data can be transmitted on subsequent passes by the orbiter. An alternative to this scenario would be to deploy the haze/penetrator probe over a buoyant station with data transmission to the station for subsequent relay to the orbiter. This would greatly relax the penetrator descent time constraint and also allow continued operation of the haze probe experiments during descent below 100 km.

HAZE/PENETRATOR PROBE DEPLOYMENT SEQUENCE



LARGE BUOYANT STATION PACKAGED IN TITAN ENTRY PROBE

This schematic drawing shows the various hardware elements of the buoyant station system packaged in a standard entry probe configuration. Although certainly not intended as an engineering drawing, the aeroshell dimensions are shown approximately to scale. The diameter is 2.5 meters which is about twice the size of the Galileo probe. The aeroshell size is driven mainly by the hydrogen gas storage system and the packed volume of balloon material. Illustrated here is a toroidal tank design with the balloon fabric packaged in the center opening. An alternative design would be multiple spherical tanks around the periphery. Other equipment shown includes a pilot chute to pull off the aft aeroshell, a second parachute to further slow the descent and pull out the balloon fabric at initiation of gas fill, the payload gondola containing the science instruments and supporting subsystems, the RTG power source shown by example as two units on deployable booms, the tether material and reel system, and the surface science package attached to the tether.



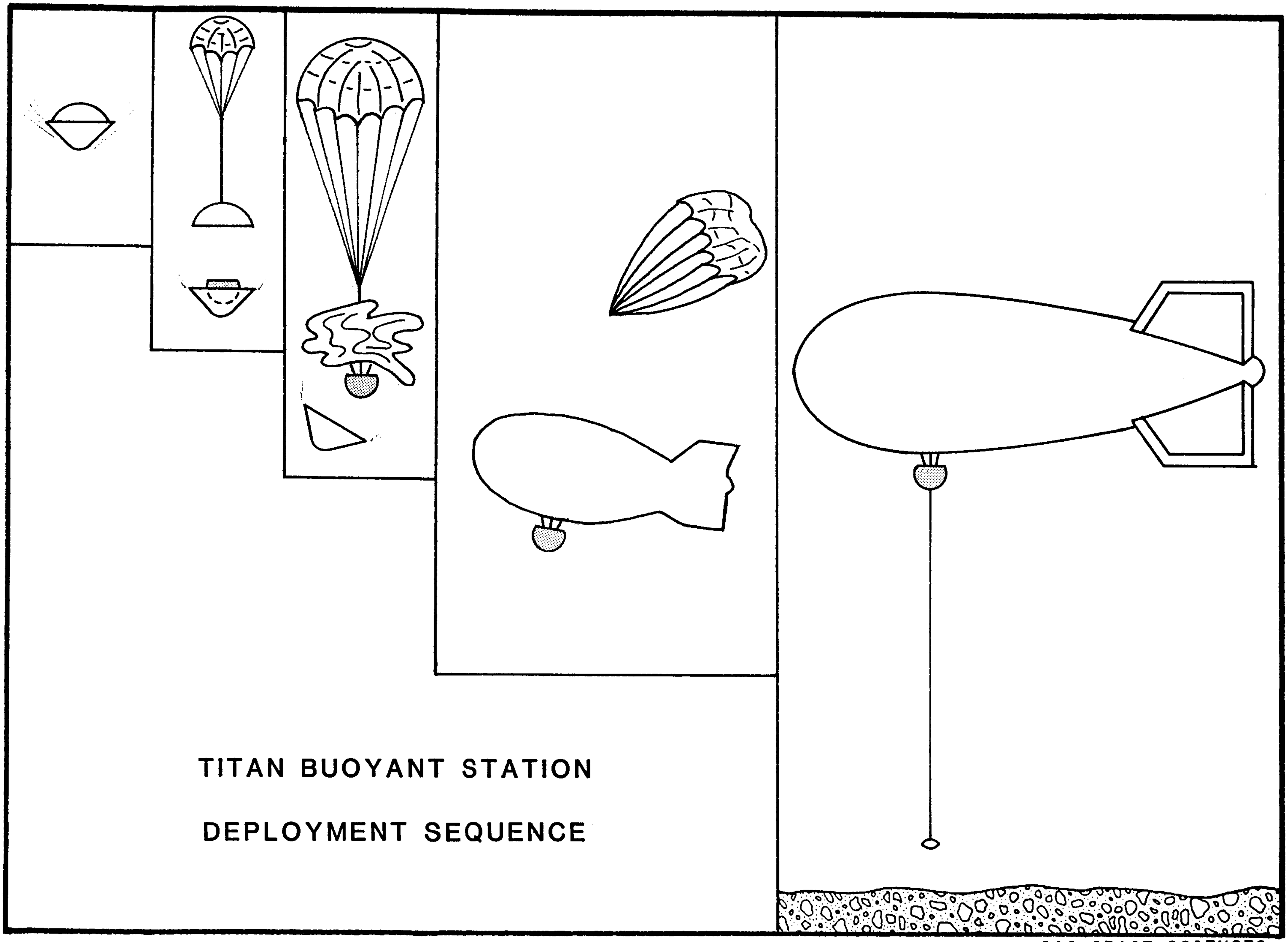
LARGE BUOYANT STATION PACKAGED IN TITAN ENTRY PROBE

MISSION CONCEPT #4

TITAN BUOYANT STATION DEPLOYMENT SEQUENCE

The cartoon drawing shows the deployment of the low-altitude buoyant station configured as a blimp or airship. Mach 1 speed is reached on atmospheric entry at about 100 km altitude. At this time the pilot chute separates the aft aeroshell and the main chute is deployed to slow the descent. Subsequently, the parachute (possibly a third chute) assists in drawing out the balloon material to commence the gas fill operation. In the nominal design, the hydrogen gas is stored under pressure (4500 psi) and flows into the balloon envelope at a maximum rate of 1.2 kg per minute. Sufficient time is available to complete the fill process during descent to 5 km altitude since the expanding envelope volume creates air drag which further slows the descent speed. One possible gas fill mode begins at high altitude ($\approx$50 km) employing a variable gas flow rate controlled by a pressure sensor to limit the balloon superpressure (above ambient atmospheric pressure) to some maximum stress level (e.g. 50 mbar) that can be withstood by the thin film material. In this case the gas fill operation is completed in about 1.5 hours as the balloon approaches its equal pressure, equilibrium altitude of 5 km. An alternative fill mode would employ a constant gas flow rate beginning at a lower altitude (e.g. 15 km) in order to keep within the superpressure limit; this operation takes less than one-half hour to complete at a flow rate of 1.2 kg/min. The first option seems preferable given various uncertainties in ambient conditions and system performance.

The cartoon does not show the buoyant gas tanks which are attached and jettisoned only after gas fill. But they are there and comprise a significant fraction of the total system mass and volume prior to and during balloon deployment. After tank jettison and some venting of gas, the station slowly settles into its design floatation altitude. Nominal balloon operation is basically at equal pressure/equal temperature equilibrium with the ambient atmosphere. However, control of vertical motion will undoubtedly be necessary throughout the two month mission, particularly during tether system operations and in response to unpredicted changes in ambient conditions and buoyant gas permeability loss. This control can be provided in several ways acting together or in concert, e.g. RTG heat source, aerodynamic lift, reserve gas, and possibly by ballast mass if necessary.



TITAN BUOYANT STATION

DEPLOYMENT SEQUENCE

SAI SPACE SCIENCES

KEY PERFORMANCE ANALYSIS

BALLOON DESIGN OPTIONS

Assuming an equal pressure balloon design for floatation at operational altitude, performance requirements were analyzed for three buoyancy options: hydrogen gas, helium gas, and thermally raised atmospheric gas. Load lift efficiencies are given in terms of two measures: the ratio of mass aloft to mass of gas carried, and the ratio of mass aloft to mass of air displaced. For the buoyant gases, hydrogen is clearly superior in the first measure but only marginally better in the second which determines the balloon envelope requirement. The "hot" air balloon is somewhat of a misnomer since the optimal superheat is only 5 to 15 K above the ambient temperature depending on floatation altitude and specific mass of the heat source. It was found, however, that the hot air balloon has good performance characteristics in the lower atmosphere of Titan; potentially better than hydrogen gas at altitudes below 50 km. Nevertheless, we chose to discount this option at the present time because of uncertain problems in deployment during descent including possible thermal lags in using the RTG heat source. Helium is a commonly used balloon gas and could be transported in pressurized tanks made of lightweight titanium. Hydrogen could be stored as a pressurized gas, or cryogenically, or bound in chemical compounds. Cryogenic storage is potentially very efficient for a large mass of gas, but the long transit time to Titan is a negative factor regarding thermal control and gas loss through venting requirements. Also, thermal energy is needed to convert the liquid hydrogen to gaseous form within a limited time interval during descent. Chemical storage may be competitive by storage system weight and volume but, again, the gas must be released by applying external energy. <u>We have selected the option of hydrogen gas stored under pressure</u> using a composite, Kevlar-wound stainless steel tank design (titanium cannot be used because of hydrogen embrittlement).

The most critical factor in balloon material selection is ductility or flexibility at the extremely low temperatures in the Titan atmosphere. Mylar is a commonly used balloon material and has fairly good low temperature properties. Kapton film has about the same density but better low temperature behavior. Other factors in the selection are high tensile strength and low permeability to gas leakage. <u>We have tentatively selected Kapton</u>, but possibly a better choice would be a composite Kapton/Kevlar envelope if this could be fashioned as a balloon material. Kevlar (Aramid fiber) is an excellent choice of material for the tether; its tensile strength is much greater than needed assuming a low wind, nonturbulent environment at low altitude above Titan. Kevlar and copper strands could also be wound together to form a conductive tether for data transmission purposes.

BALLOON DESIGN OPTIONS

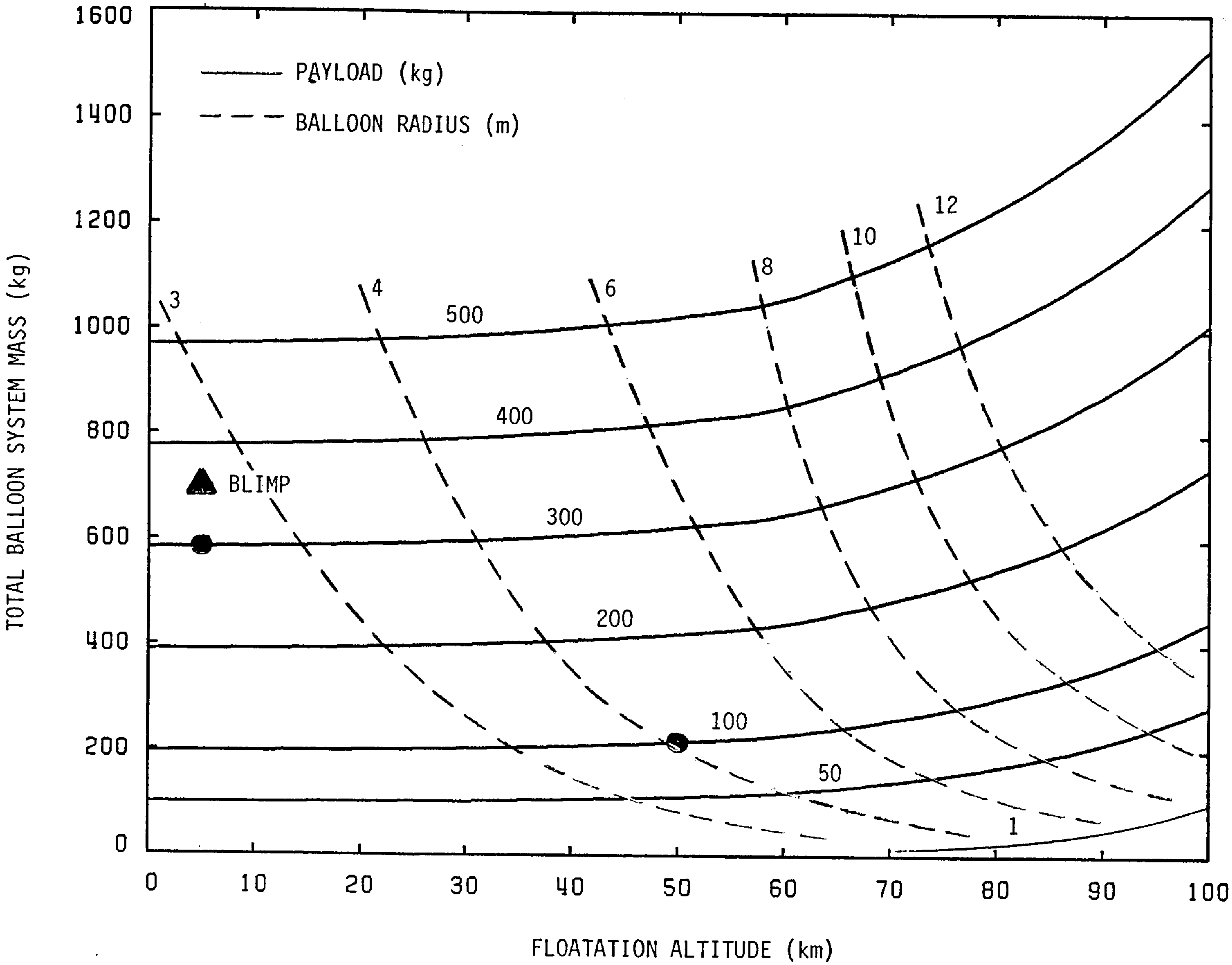
BUOYANT GAS	MOL. WEIGHT RATIO $\beta = \overline{M}_G/\overline{M}_a$	LOAD LIFT EFFICIENCIES $M_L/M_G = \beta - 1$	$M_L/\rho_a V_B = \frac{\beta - 1}{\beta}$	GAS TRANSPORT
√ HYDROGEN	14	13	0.929	√ PRESSURIZED, CRYOGENIC, CHEMICAL
HELIUM	7	6	0.857	PRESSURIZED
'HOT' AIR ($\beta = 1 + \frac{\Delta T}{T}$)	≈1.10	—	≈0.090	NONE, HEAT SOURCE REQ'D

BALLOON MATERIAL	MATERIAL TYPE	DENSITY g/cc	TENSILE STRENGTH (psi)	LOW TEMPERATURE BEHAVIOR
MYLAR	FILM	1.4	20,000	GOOD
√ KAPTON	FILM	1.4	35,000	VERY GOOD
KEVLAR	FABRIC	1.4	200,000	VERY GOOD
√ KEVLAR (ARAMID) TETHER	FIBER 2 mm diam.	2 kg/km	340,000	

HYDROGEN BUOYANT BALLOON PERFORMANCE AT TITAN

Total balloon system mass is comprised of the gas, gas storage system, envelope fabric, and payload. The performance map on the facing page shows the system mass vs. floatation altitude characteristics for constant values of payload mass and balloon radius parameters. Note that system mass does not vary significantly with altitude below 60 km even though the balloon radius at constant payload does increase substantially. This simply reflects the relatively small mass of fabric and gas as a fraction of total system mass. Nominal design points are indicated for the small* balloon floating at 50 km and the large* balloon and blimp at 5 km altitude. Details of these nominal designs wil be described later.

* Small or large refers here to mass and not balloon dimensions.



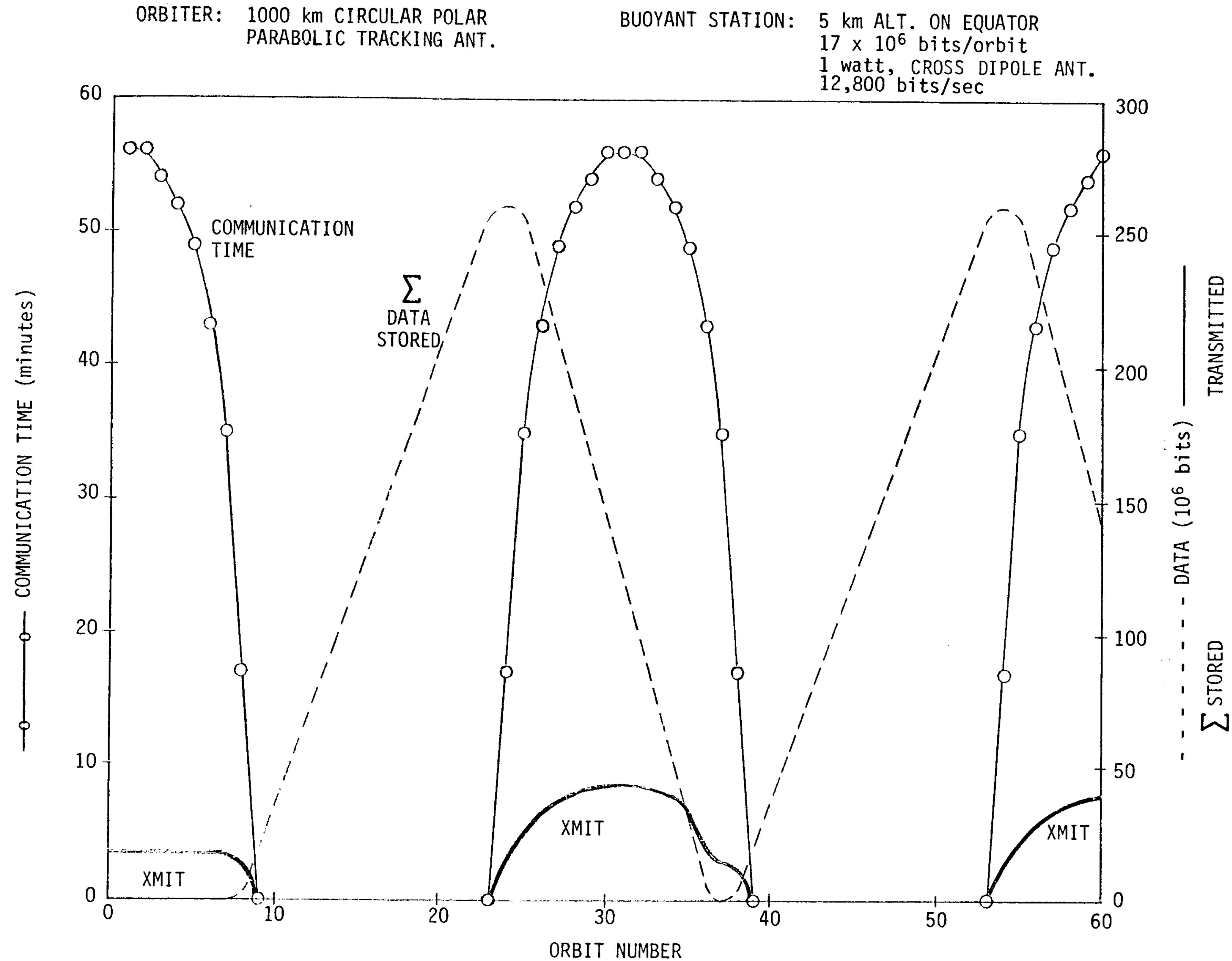
HYDROGEN BUOYANT BALLOON PERFORMANCE AT TITAN

LARGE BUOYANT STATION-TO-ORBITER DATA COMMUNICATIONS

Because of its desired equatorial location and high data accumulation, the large buoyant station communicating with a polar orbiter is the driver on relay link requirements. An analysis of this worst case situation shows that communications is not really a problem, with the caveat that the buoyant station will have to "go it alone" for an interval of time in a repetitive cycle.

The illustration on the facing page describes this cycle in terms of communication time, data transmitted, and data stored. The station accumulates science data at the average rate of 17×10^6 bits per orbiter period (3.93 hours). It transmits during periods of visibility at the rate of 12,800 bits/sec (3 dB minimum data margin) using a 1 watt transmitter and a cross dipole antenna; the orbiter receives this signal using a parabolic tracking antenna (22 dB gain, 12.6° half-power beamwidth).

With the orbiter overhead on the first orbit, the maximum communications time is 56 minutes. This time drops off to a minimum of 17 minutes as the orbiter moves out of the zenith plane, and visibility ends on the 9th orbit pass. The buoyant station must then store its accumulating data for an interval of 15 orbits ($\simeq$ 60 hours) to a maximum data storage requirement of 262×16^6 bits -- well within the capability of current spacecraft tape recorders. The relay link is regained on the 24th orbit and the stored data is downloaded on succeeding visible orbits. The maximum data transmission during this interval is 43×10^6 bits per orbit. This cycle repeats (approximately) every 30 orbits as Titan rotates and the station moves in longitude. The link visibility duty cycle is approximately 50%.



LARGE BUOYANT STATION-TO-ORBITER DATA COMMUNICATIONS

SPACECRAFT DESIGN BASIS FOR MASS ESTIMATION

Although the proposed mission to Titan would certainly be a major new start and involve some hardware elements never before designed or tested, there is the opportunity for significant heritage from ongoing projects in the core program of planetary exploration. Such design heritage includes various spacecraft components, subsystems, entry probes, bus configurations, and science instruments. The data base indicated was used as input to sizing analysis to arrive at mass estimates for the hardware elements required for the Titan mission concepts under investigation.

Titan orbit capture is a relatively demanding process of trajectory energy management. The system options studied include: (1) chemical propulsion; (2) aerocapture; and (3) nuclear electric propulsion. In the case of all-chemical propulsion, we assume an earth-storable bipropellant system having a specific impulse of 295 seconds. On approach to Saturn, the 3-impulse maneuver strategy is: Saturn orbit insertion, apoapse plane change and periapse raise, and finally Titan orbit insertion. The aerocapture option is ideally suited for direct insertion into a close orbit of Titan, then requiring only a small propulsion system for periapse raise out of the atmosphere and subsequent orbit trim maneuvers. Aerocapture vehicles for Saturn/Titan mission applications have been studied extensively in recent years. The last option for mass delivery is the very capable nuclear electric propulsion (NEP) which can operate all the way from low Earth orbit to low Titan orbit. Performance calculations in this study assume a 100 kwe reactor source driving ion engines operating at a specific impulse of 5500 seconds. A system of this type is currently being studied by DOE and NASA.

SPACECRAFT DESIGN BASIS FOR MASS ESTIMATION

- BUOYANT STATION ENTRY PROBES.........TITAN (GALILEO) DECELERATION MODULE
  SCALED TO LARGE DESCENT PAYLOAD

- TITAN FLYBY PROBE CARRIER...........HUGHES TITAN (GALILEO) DESIGN & PIONEER VENUS
  MODIFIED FOR LARGER PROBES

- ORBITER-DEPLOYED ENTRY DEVICES.......MARS PENETRATOR SYSTEM DESIGN
  AMES HAZE PROBE CONCEPT
  LAUNCH TUBE, DEPLOYABLE FABRIC DECELERATOR

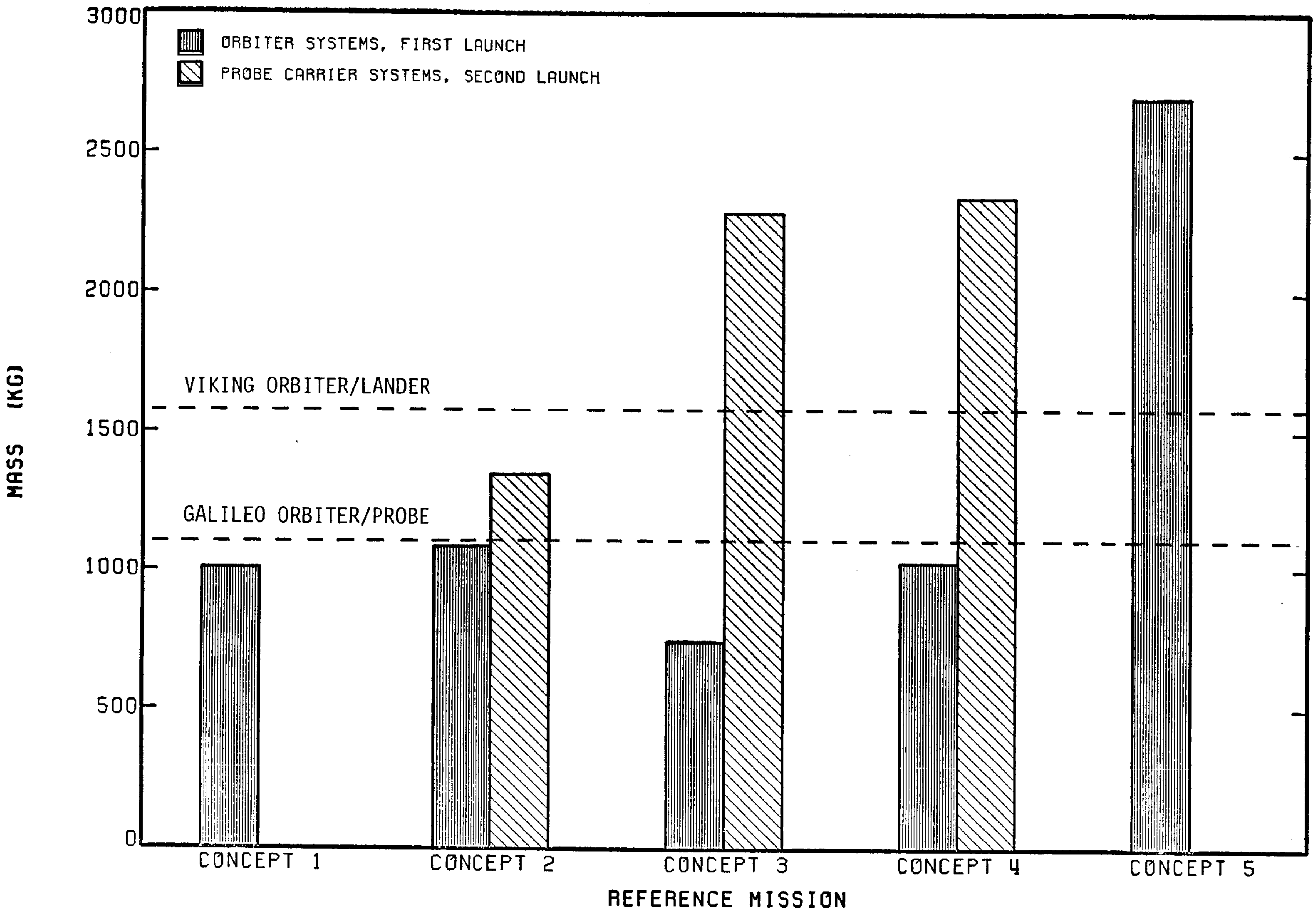
- TITAN ORBITER BUS...................MARINER MARK II (SATURN ORBITER)
  MODIFIED FOR LAUNCH TUBE ENTRY DEVICES

- ORBIT CAPTURE OPTIONS...............3-IMPULSE CAPTURE, CHEMICAL PROPULSION
  AEROCAPTURE VEHICLE, BIPROPELLANT ORBIT TRIM
  SPIRAL CAPTURE, NUCLEAR ELECTRIC PROPULSION

HARDWARE MASS ELEMENTS

Results of the mass sizing analysis are summarized by the bar chart on the facing page. The mass shown comprises all spacecraft bus and probe systems including science payloads, but excludes the main propulsion systems or its equivalent needed for mass delivery (i.e. chemical propulsion, aerocapture, or nuclear electric propulsion are not included here). As a point of reference, the same measure of mass for Viking Orbiter/Lander and for Galileo/Orbiter/Probe is indicated. This illustration offers proof by this measure that a Titan intensive mission is indeed in the category of an augmentation to the SSEC core program of planetary exploration. Only mission concept 1, which does not include any buoyant stations, has a total mass complement below the Galileo or Viking hardware.

TITAN INTENSIVE STUDY - HARDWARE MASS ELEMENTS (KG) EXCLUDING MAIN PROPULSION



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BUOYANT STATION PROBE MASS BREAKDOWN

Detailed mass statements for the small balloon and large blimp systems are tabulated on the facing page. Floatation requirements (gas, storage tanks and balloon envelope) assume nominal operation at 50 km altitude for the small balloon and at 5 km altitude for the blimp. The blimp propulsion unit (electric engine and propellant) is sized a maximum horizontal speed of 5 m/sec in the atmosphere; the corresponding electric power requirement to overcome air drag is 210 watts. The relatively large RTG power source for the blimp provides 500 watts of electric power to the payload and 1000 thermal watts used intermittently for buoyancy control. Total station payloads including science and support subsystems are 100 kg for the small balloon and 360 kg for the blimp. Adding the buoyant gas, reserve, and envelope fabric brings the total floated mass to 127 kg and 414 kg, respectively, for the two applications. The gas transport system assumes a Kevlar wound stainless steel tank design (containing the gas at 4500 psi pressure) and is estimated to weigh 9 times the amount of floatation gas with ample margin allowed for in-transit losses and present design uncertainty. Total entry probe mass including the aerodeceleration module (scaled from current Titan probe designs) is 296 kg for the small balloon and 921 kg for the blimp, i.e., respectively, about equal to and three times the mass of the Galileo probe. Aeroshell diameters are about equal to and twice the size of the Galileo probe for the two cases.

BUOYANT STATION PROBE MASS BREAKDOWN

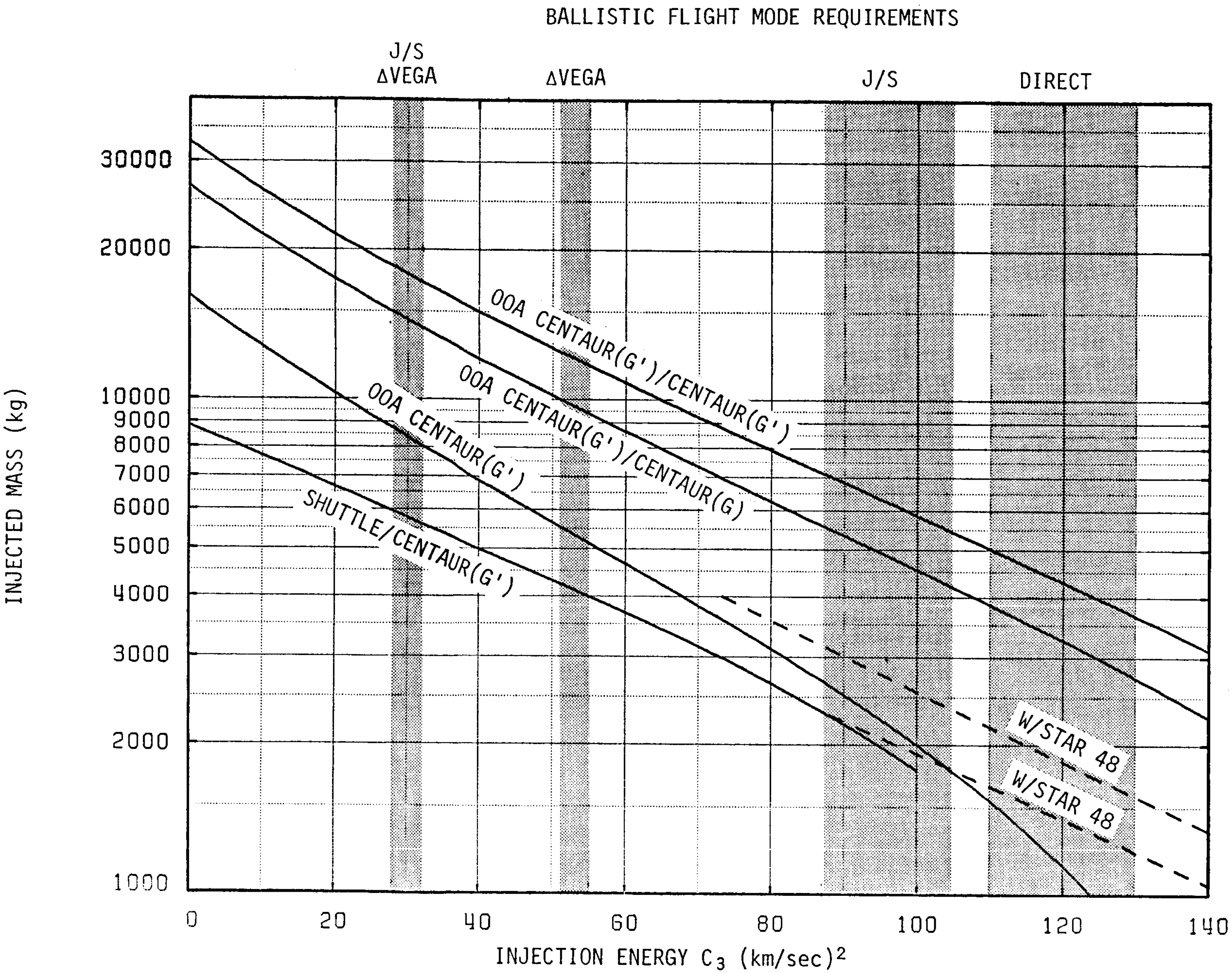
STATION SUBSYSTEM	50 km SMALL BALLOON		5 km LARGE BLIMP	
SCIENCE	20 kg		80 kg	
STRUCTURE & DEVICES	28		85	
THERMAL CONTROL & CABLING	12		25	
TELECOMMUNICATIONS	11		11	
COMMAND & DATA	14		23	
POWER & HEAT SOURCE*	15		102*	
PROPULSION	—		14	
TETHER SYSTEM	—		20	
TOTAL STATION PAYLOAD	100		360	
H_2 BUOYANT GAS	10		32	
RESERVE GAS & TANK	5		15	
BALLOON FABRIC (DIAMETER)	12	(8.2 m)	7	(11.9 x 4 m)
TOTAL FLOATED MASS	127		414	
GAS TRANSPORT	90		288	
TOTAL ENTRY PAYLOAD	217		702	
AERODECELERATION MODULE	79		219	
TOTAL ENTRY PROBE MASS	296 kg		921 kg	

* 500 watts electric
1000 watts thermal use
5100 watts thermal dump

LAUNCH VEHICLE PERFORMANCE

Four candidate launch systems that span the range of capability needed for advanced missions to Titan are considered in this study. Of these, only the lowest performing system - the Shuttle/-Centaur(G') - is actually under development for first use in the 1986 Galileo mission. The other systems assume future technology developments in on-orbit assembly (OOA) or fueling. For example, the system designated OOA Centaur(G') refers to fully loading the propellant tanks of the Centaur (G') injection state; normally these tanks may have to be offloaded on the ground due to the 65,000 lbm cargo limitation of the existing Shuttle launch vehicle. The performance gained by on-orbit fueling can be significant, especially in the region of low injection energy. The next step in capability is to mate two Centaur stages together on-orbit, either by means of Shuttle crew-directed operations or at some future Space Station operational base. Note that the (G) designation is the smaller Air Force version of the Centaur vehicle.

The figure also indicates the range of injection energy required for various ballistic transfer modes to Saturn, e.g. ΔVEGA and direct. The J/S transfers refer to the unique Jupiter swingby opportunities which next occur in the late 1990's but do not repeat again for 20 years.



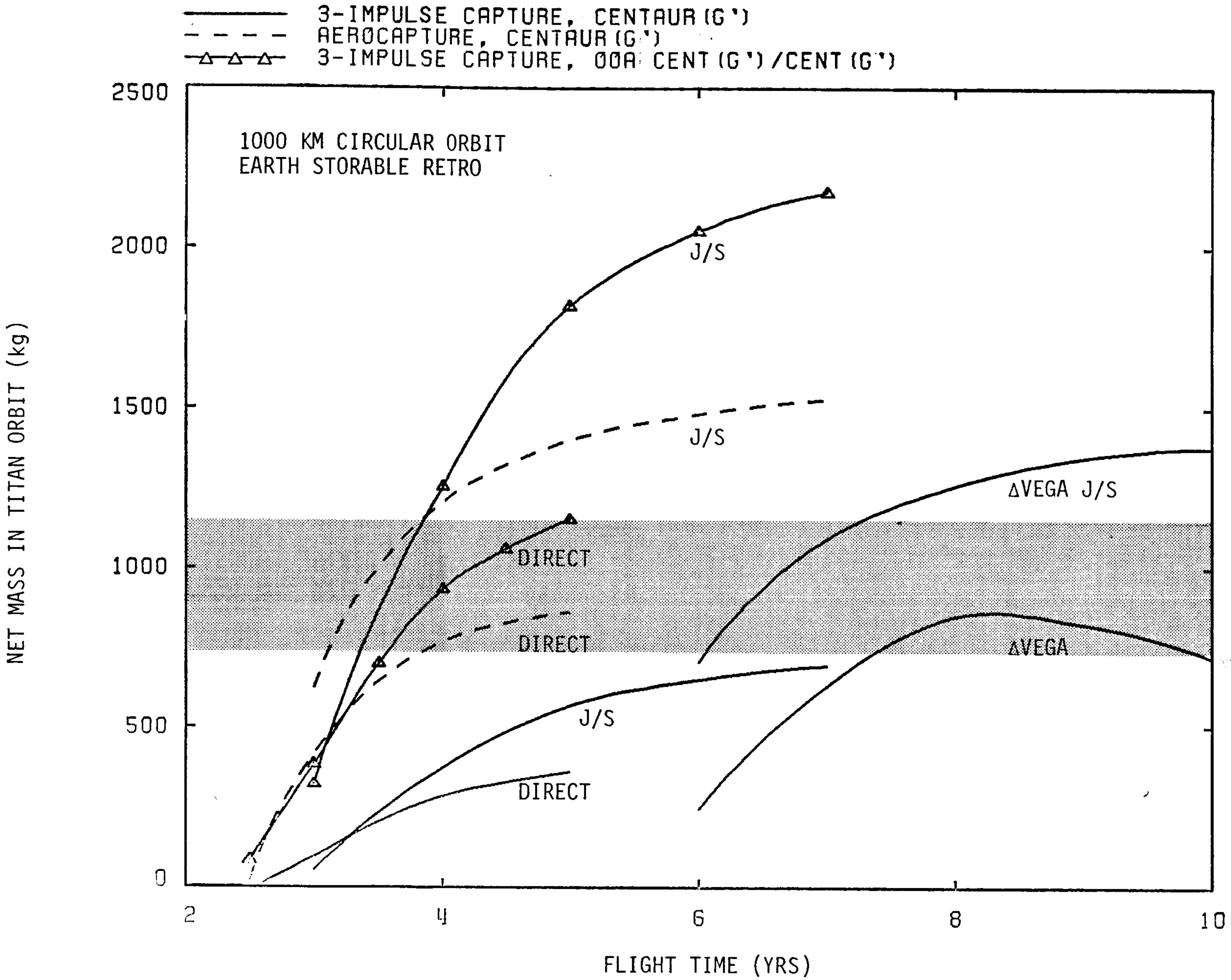
LAUNCH VEHICLE PERFORMANCE

TITAN ORBITER DELIVERY PERFORMANCE - BALLISTIC FLIGHT MODE

Net mass placed into orbit about Titan is defined as the mission hardware elements (orbiter science, subsystems and entry probes) exclusive of propulsion systems or aerocapture vehicle. The range of net mass requirement for the various ballistic mission concepts has been determined to be 740-1145 kg. The ΔVEGA capability with Shuttle/Centaur(G') just barely makes it into this range and the flight time is 8 years. When matched with the best Jupiter swingby launch opportunity in 1998, ΔVEGA does capture these missions for flight times between 6 and 7 years.

Shorter flight times of interest require direct Earth-Saturn trajectories or direct trajectories with Jupiter swingby. Shuttle/Centaur(G') does not have sufficient capability without the use of Titan aerocapture. With aerocapture, only the J/S opportunity provides adequate performance for flight times between 3 and 4 years.

If the J/S opportunity is discounted because the launch is too early for the type of missions considered in this study, then on-orbit assembly technology may be required. The possible options include OOA Centaur(G')/Centaur(G') for direct flights without aerocapture, or OOA Centaur(G') with aerocapture (not shown on the graph). Flight times under 5 years are possible in these cases.

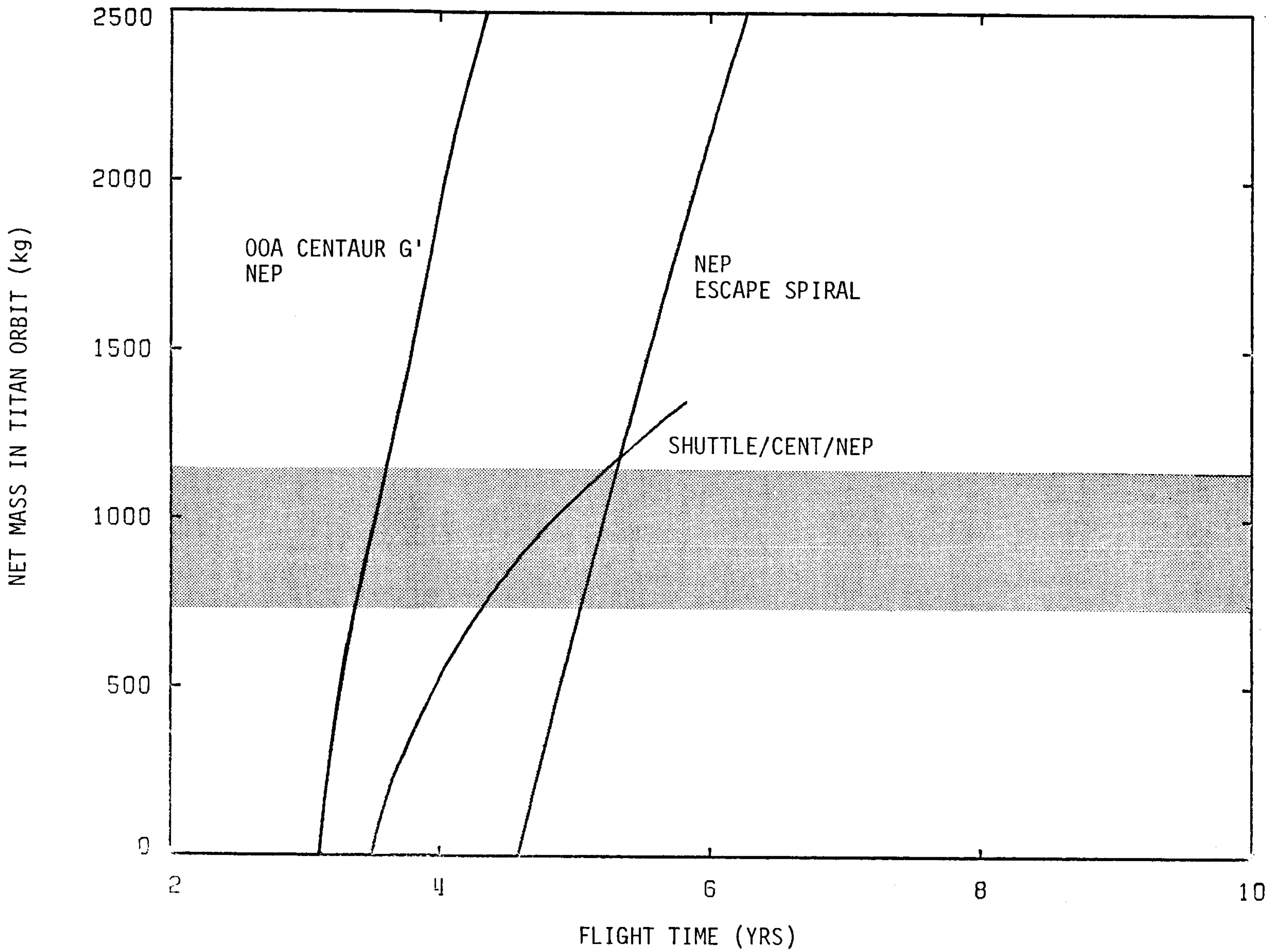


TITAN ORBITER DELIVERY PERFORMANCE - BALLISTIC FLIGHT MODE

TITAN ORBITER DELIVERY PERFORMANCE - NEP FLIGHT MODE

NEP flights can be implemented in either of two modes: Earth escape spiral and direct injection to escape energy $C_3 \geq 0$. In the first mode, NEP thrusting is initiated in a "nuclear safe" low circular orbit (taken here as 700 km) and spirals slowly upward until the escape condition $C_3 = 0$ is attained after approximately one year; it then continues on its direct heliocentric transfer to Saturn. No chemical injection stage is required. The Shuttle can deliver the NEP/spacecraft system to 700 km altitude with the use of two OMS propulsion kits; the cargo capability is about 20,000 kg. In the second mode, the escape spiral is eliminated with potential savings in flight time, but an injection stage like Centaur is required.

Performance of these two flight modes is illustrated on the facing page. The standard Shuttle/Centaur(G') launch has limited capability because of the large mass of the combined NEP/spacecraft system, thereby necessitating offloading the Centaur propellant tanks. The range of required net mass in Titan orbit is captured with flight times of 4.3 to 5.1 years. However, the 2700 kg requirement of Mission Concept #5 cannot be captured by this launch option. Either the escape spiral mode or direct injection with a fully loaded Centaur (on-orbit Δ fueling) would be needed for this concept. The respective flight times for delivery of 2700 kg to Titan orbit are 6.5 and 4.5 years. Note that the orbited payload range of Mission Concepts 1 through 4 (740-1145 kg) could be captured by the OOA Centaur option with a flight duration of only 3.5 years.



TITAN ORBITER DELIVERY PERFORMANCE - NEP FLIGHT MODE

MISSION PROFILE AND COST SUMMARY

PROFILE DATA FOR TITAN MISSION CONCEPT #4

This is the most demanding of our mission concept selections in terms of the number of hardware elements and science experiment operations. Baseline choices were made on the basis of performance capability related to advanced technology development requirements for payload delivery systems and consideration of their likely availability. Other choices are possible and could be examined in follow-on studies. In making the baseline selections we have opted for short flight time ballistic transfers with the use of aerocapture for the Titan orbiter. The additional technology required is on-orbit fueling and assembly of Centaur injection stages.

The Titan orbiter mission is launched first in July 1999* and arrives at Titan after a flight time of 4.5 years. The spacecraft bus carrying the buoyant station probes is launched a year later in July 2000 and arrives 8 months after the orbiter. In the meanwhile, the orbiter is performing its science investigation mission from a close polar orbit about Titan. This mission includes global mapping with radar and near IR imaging, and deployment of 3 haze probes. With the imaging systems hypothesized and a data transmission limit of 2×10^6 bits/sec (3.7 m HGA, X-band), it is estimated that nearly global coverage without overlap requires about 1000 orbits or 5.5 months. This assumes, on average, a 50% duty cycle over time for the operations of data accumulation and data transmission to Earth when the link is not occulted by Titan. Additional time is available as needed prior to support of the buoyant station missions and perhaps after in an extended orbiter mission program.

Total injected mass requirements for the orbiter and probe carrier launches are 1885 kg and 2730 kg, respectively. Injected mass margins are 120 kg and 970 kg for the selected launch stages.

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* The launch year listed is by way of example, keeping with the desire that this mission be underway before the turn of the century. Later launches are possible and may be necessary in response to the implemented schedule of precursor missions to Titan.

PROFILE DATA FOR TITAN MISSION CONCEPT #4

	1st LAUNCH	2nd LAUNCH
HARDWARE ELEMENTS	IMAGING ORBITER LTD HAZE PROBES (3) AEROCAPTURE VEHICLE	LARGE BLIMP ENTRY PROBE SMALL BALLOON ENTRY PROBES (3) PROBE CARRIER
LAUNCH STAGE	OOA CENTAUR(G')/STAR 48	OOA CENTAUR(G')/CENTAUR(G)
FLIGHT MODE	DIRECT BALLISTIC, AEROCAPTURE	DIRECT BALLISTIC, FLYBY
LAUNCH DATE	JULY 1999	JULY 2000
FLIGHT TIME	4.5 YEARS	4.2 YEARS
ARRIVAL DATE	JAN 2004	SEP 2004
OPERATING TIME	10 MONTHS	2 MONTHS
TOTAL INJECTED MASS	1885 KG	2730 KG
INJECTED MASS MARGIN	120 KG (@ C_3 = 115)	970 KG (@ C_3 = 112)

COST ESTIMATES FOR TITAN MISSION CONCEPT #4

Cost estimates for the individual elements which comprise Titan Mission Concept #4 are shown as an example of the method used for cost estimation. Hardware development refers to the design, fabrication, assembly and test of a fully flight-qualified spacecraft, i.e. cost of the vehicle prior to launch stack integration. Each vehicle is treated as an independent development project, with its own project management, hardware development and spacecraft-level integration and test cost elements. Further details may be found in the Appendix to this report.

The program-level elements consist of activities which apply either only before launch, as in subcontracting and vehicle integration, only after launch for science data analysis, or throughout the entire mission program, as in operations and management. For this costing scenario, it has been presumed that all hardware elements except the orbiter are developed via the major system contract mode. Thus, subcontracting refers to costs associated with monitoring and administering these system contracts. Vehicle integration refers to costs associated with assembling the various spacecraft into a launch/flight stack. In the case of Mission Concept #4, this is the summation of the costs for two separate stacks. Mission operations includes costs for mission design, launch operations and cruise and encounter operations. Shared cruise operations have been assumed such that to a first order approximation there is no marginal cost increase when two flight assemblies are simultaneously in transit. Data analysis encompasses the costs of cataloging and analyzing the returned science data and, in general, is a function of the number and complexity of science investigations and the nominal encounter duration. Program management includes costs for integrating and managing the various other elements into a cohesive program. Finally, because of the preliminary yet ambitious concept for such a mission as this to Titan, a liberal contingency of 30% has been applied to the net cost estimate, leading, in the case of Mission Concept #4, to a total cost estimate of nearly $1.6 billion.

COST ESTIMATES FOR TITAN MISSION CONCEPT #4

		FY'84 $M
HARDWARE DEVELOPMENT PROJECTS		930.4
TITAN ORBITER	234.4	
HAZE DEVICES (3)	112.0	
AEROCAPTURE VEHICLE	93.4	
PROBE CARRIER	110.1	
BALLOON PROBES (3)	168.5	
BLIMP PROBE	212.0	
PROGRAM-LEVEL ELEMENTS		289.5
SUBCONTRACTING	104.4	
VEHICLE INTEGRATION	37.6	
MISSION OPERATIONS	98.2	
DATA ANALYSIS	39.0	
PROGRAM MANAGEMENT	10.3	
CONTINGENCY (30%)		366.0
TOTAL		1585.9

SHUTTLE AND CENTAUR LAUNCH COSTS NOT INCLUDED

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MISSION CONCEPT COST SUMMARY AS RELATED TO SCIENCE INVESTIGATION

The mission concept chart shown previously has been recast as a way of summarizing the development project/operations costs. The number of science experiments performed by each hardware element in a given mission concept is listed; these are distinct experiments and multiple deployments (e.g. 3 probes or 3 balloons) are not counted multiply. Also note that the number of experiments carried by a surface package is not specified because of uncertain definition at this time; rather, it is assumed that they are counted in the buoyant station complement of instruments. Numbers in parentheses refer to the flyby probe carrier elements in the dual launch scenarios.

The last two columns of the chart show the total number of experiments and total project cost estimate for each concept. As stated earlier, Mission Concept #1 represents a minimum capability investigation and does not include any buoyant stations. There are 15 experiments and the estimated cost is about three quarters of a billion dollars. At the high end of capability, Mission Concept #4 has 28 experiments and would cost about one and a half billion dollars.

It is not at all surprising to find a strong correlation between number of experiments and cost. Another way of looking at the cause and effect cost relationship would be to add up all of the different hardware elements comprising each mission concept. A correlation would again be found. Past studies such as Mars Sample Return have shown that costs invariably add up with the number of distinct hardware elements included, this being a measure of mission complexity and performance capability.

TITAN ATMOSPHERE AND SURFACE INVESTIGATION - MISSION CONCEPTS

NUMBER OF SCIENCE EXPERIMENTS AND MISSION COST

CONCEPTS	FLYBY PROBE CARRIER	TITAN ORBITER		UPPER ATMOSPHERE HAZE		ATMOSPHERE				SURFACE (LIQUID OR SOLID)		SUB-SURFACE (METERS)			
						TROPOSPHERE		LOWER							
		W/O RADAR & IR IMAGER	W/ RADAR & IR IMAGER	SOUNDING ROCKET	ENTRY PROBE	DESCENT PROBE MEAS.	SOUNDING BALLOON	BUOYANT STATION (BALLOON)	BUOYANT STATION (BLIMP)	TETHERED PACKAGE	DROPPED PACKAGE	TETHER (LIQUID)	PENE-TRATOR (SOLID)	NO. OF EXP.	DEV/OPS COST FY'84 $M
1		7			4								4	15	740
2	(X)		9		4		(6)						4	23	1,260
3	(X)		9	(4)			(6)	(9)			(X)			28	1,510
4	(X)		9		4		(6)		(9)	(X)		(X)		28	1,590
5		7					6		9	X		X		22	1,070

X ORBITER-DEPLOYED SPACECRAFT ELEMENTS

(X) FLYBY PROBE CARRIER-DEPLOYED SPACECRAFT ELEMENTS

TITAN PROGRAM COST ESTIMATE WITH TRANSPORTATION INCLUDED

Since NASA must, in effect, budget the cost of transportation in a total program account, it is of some interest to estimate this additional resource requirement. Transportation is defined here to mean the recurring or "use" cost of Shuttle launches, upper stages, and on-orbit assembly operations. NEP is a special case of a high cost, extended upper stage and is included separately as part of the transportation system. Itemized costs given at the top of the chart are based on current NASA estimates for Shuttle launches and Centaur stages, and on preliminary SAI estimates of NEP and OOA. Note that all mission concepts require more than a single Shuttle launch for delivery of hardware (or propellant) to low Earth orbit. However, not all launches need the full cargo bay. We have assumed a cost sharing policy and very roughly estimated its effect.

The total cost of transportation elements over the range of mission concepts is about 200 to 400 million dollars. When added to the project incurred cost, the total program cost of a Titan-intensive science investigation increases to the range 1 to 2 billion dollars.

TITAN PROGRAM COST ESTIMATE WITH TRANSPORTATION INCLUDED

SHUTTLE.......100M/FULL LAUNCH
CENTAUR G.....35M
CENTAUR G'....45M
STAR 48.......5M
NEP...........175M
OOA...........10M/FLIGHT ASSEMBLY

FY'84 $M

MISSION CONCEPT	PROJECT COST DEVELOP./OPS	TRANSPORTATION COSTS					TOTAL PROGRAM COST
		SHUTTLE LAUNCH	UPPER STAGE	NEP	OOA	TOTAL	
1*	740	150	50	—	10	210	950
2	1,260	250	100	—	10	360	1,620
3	1,510	250	130	—	10	390	1,900
4	1,590	250	130	—	20	400	1,990
5	1,070	150	45	175	10	380	1,450

* NO BUOYANT STATIONS IN CONCEPT 1

STUDY CONCLUSIONS

KEY TECHNOLOGY ISSUES

- FOLLOW TECHNOLOGY DEVELOPMENTS AND UPDATE ASSESSMENT OF

  AEROCAPTURE
  ON-ORBIT ASSEMBLY (SPACE STATION?)
  NUCLEAR ELECTRIC PROPULSION

  WITH REGARD TO APPLICATION TIMELINESS, PERFORMANCE, AND COST.

- PACKAGING OF RTG POWER SOURCE IN AEROCAPTURE VEHICLES & ENTRY PROBES.

  HEAT REMOVAL OPTIONS
  IMPACT ON VEHICLE SIZE & MASS

- RE-EXAMINE SELECTION OF BUOYANT GAS (HYDROGEN OVER HELIUM).

  VERIFY 'LIGHTWEIGHT' (9 X M_G) TRANSPORT OF PRESSURIZED H_2 GAS
  LEAKAGE FRACTION DURING LONG TRANSIT

- BALLOON MATERIAL PERFORMANCE AT EXTREME LOW TEMPERATURES
  BALLOON DEPLOYMENT AND GAS FILL DESIGN DURING ATMOSPHERIC DESCENT

  SUBJECT TO GROUND AND FLIGHT TEST VERIFICATION

STUDY CONCLUSIONS

- FUTURE MISSION CONCEPTS HAVE BEEN IDENTIFIED THAT WOULD ACCOMPLISH A MAJOR ADVANCEMENT IN OUR KNOWLEDGE OF THE WORLD OF TITAN.

- ENGINEERING DESIGN OF SUCH A MISSION APPEARS TO BE FEASIBLE, ALTHOUGH ADVANCED TECHNOLOGY DEVELOPMENTS IN MASS DELIVERY SYSTEMS WILL BE REQUIRED. THESE DEVELOPMENTS ARE CURRENTLY UNDER STUDY BY NASA AND MAY BE IMPLEMENTED BY THE TURN OF THE CENTURY.

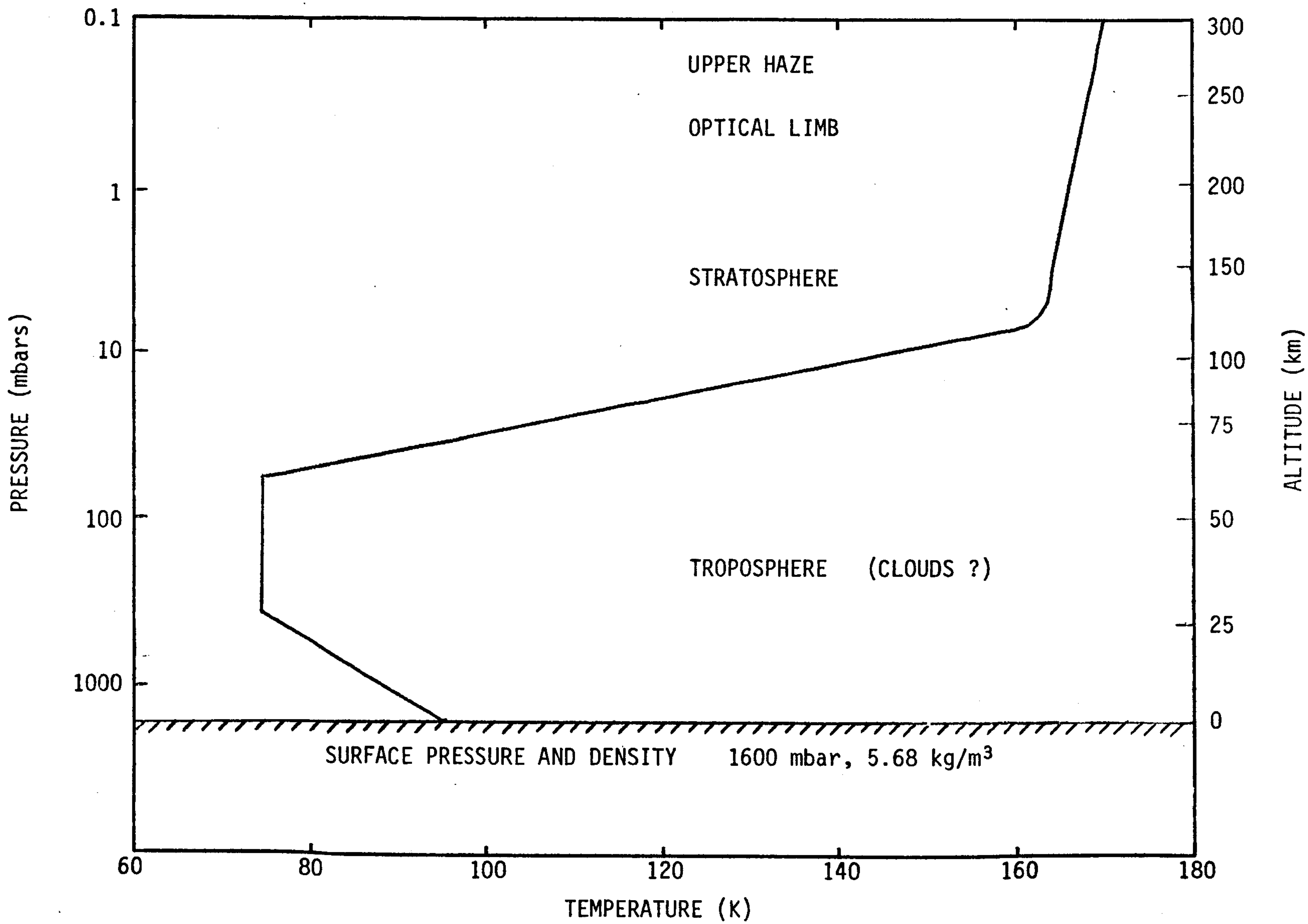
- PROJECT COST ESTIMATES OVER THE RANGE OF MISSION CONCEPTS STUDIED ARE 750 - 1500 $M, OR 1000 - 2000 $M WITH TRANSPORTATION COSTS INCLUDED.

- A TITAN-INTENSIVE MISSION REPRESENTS A POTENTIAL AUGMENTATION TO THE SSEC CORE PROGRAM ON THE BASIS OF COMPLEXITY, COST AND SCIENCE DATA RETURN.

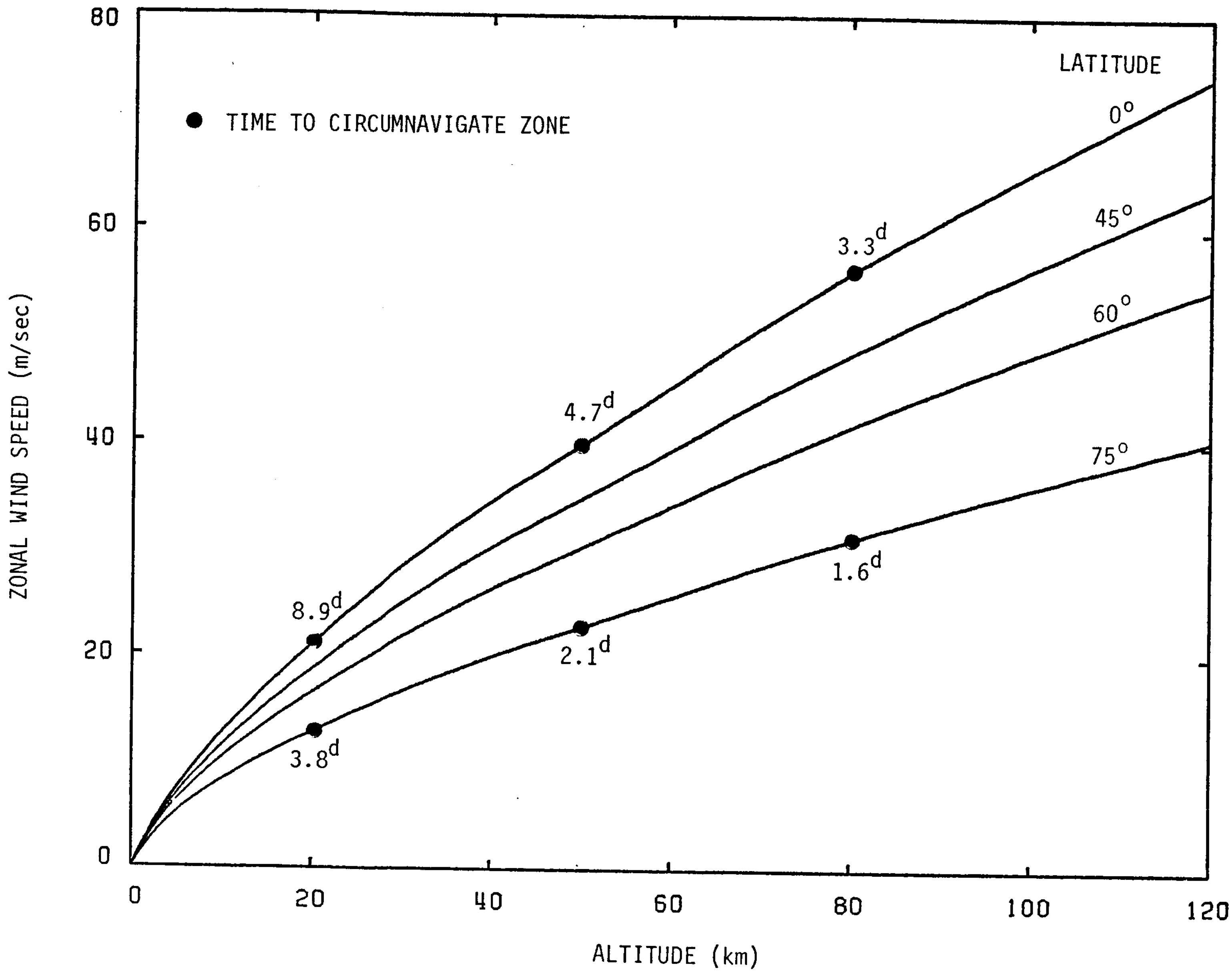
SUPPORTING DATA APPENDIX

MISSION DESIGN ANALYSIS

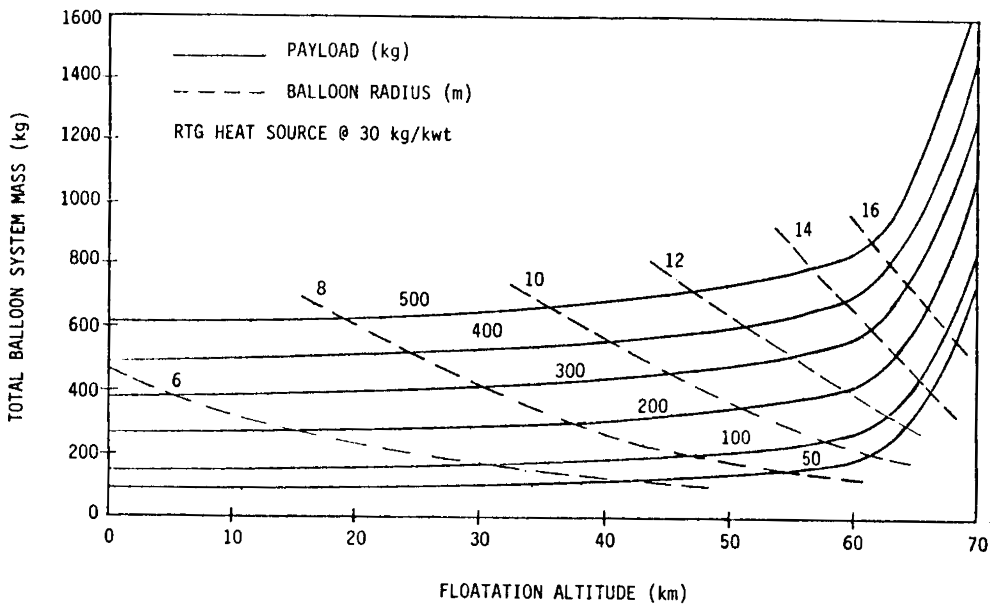
ATMOSPHERE OF TITAN - HUNTEN MODEL, VOYAGER 1 DATA



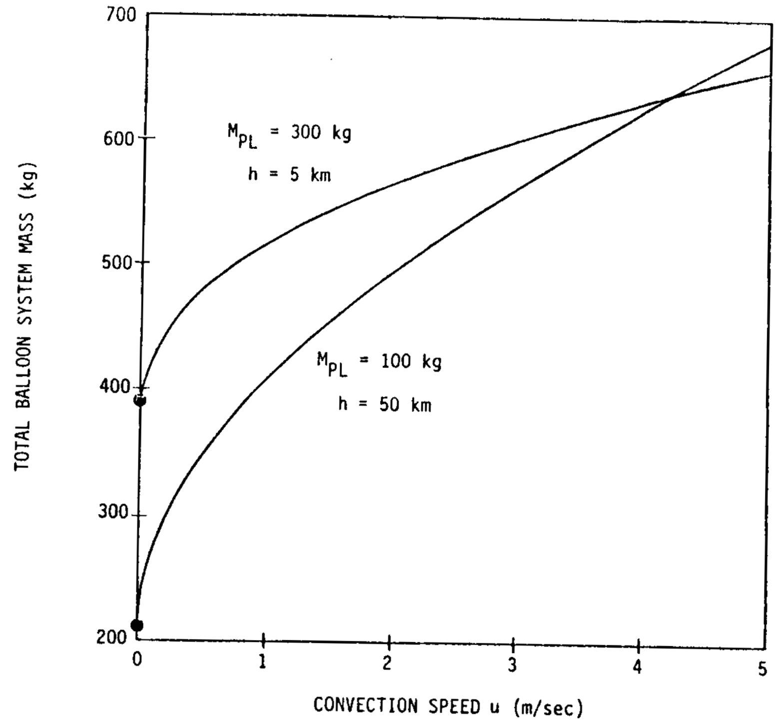
CYCLOSTROPHIC BALANCE, VOYAGER 1 THERMAL GRADIENT DATA (NATURE 8/20/81)



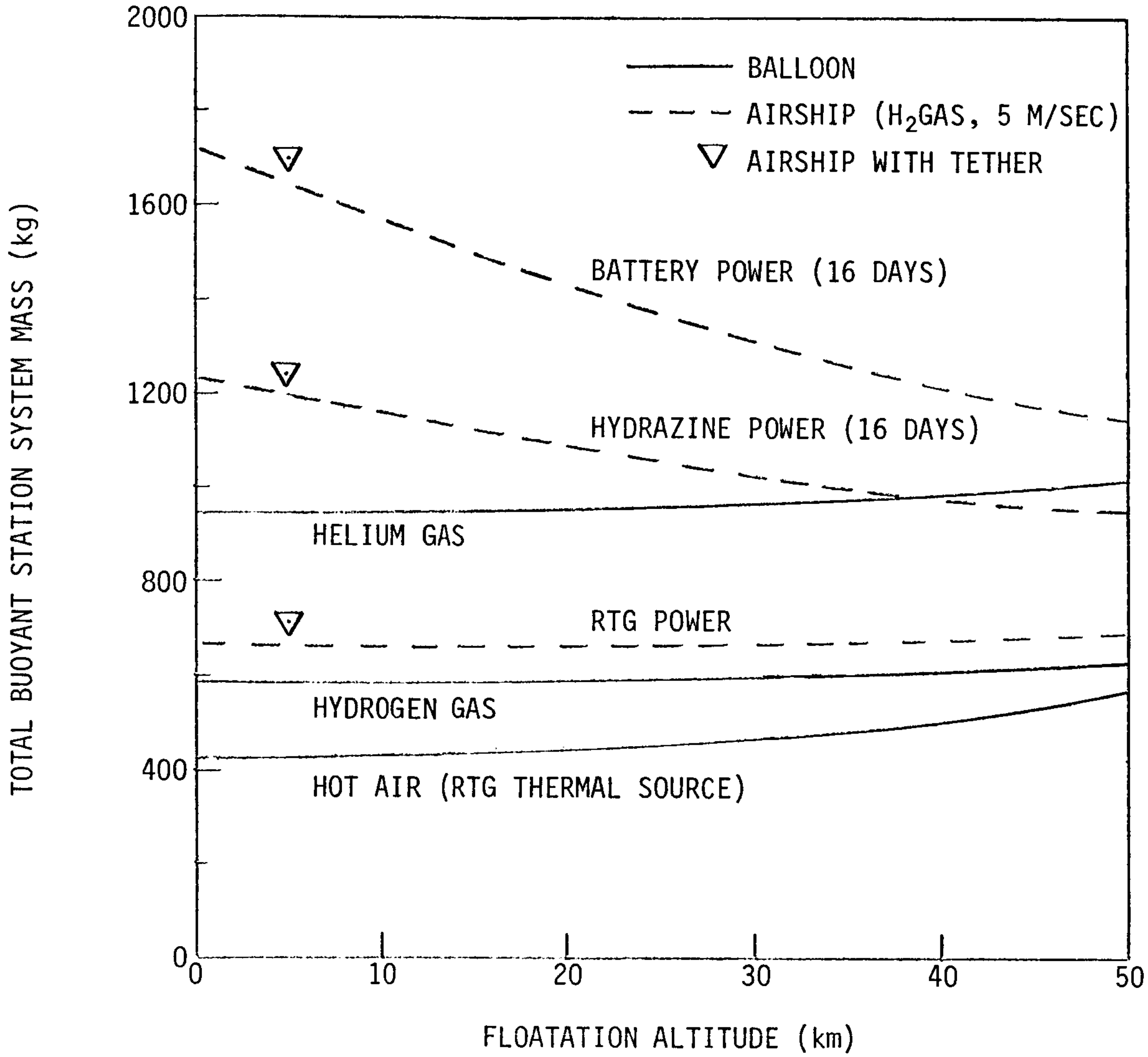
TITAN WIND SPEED MODEL



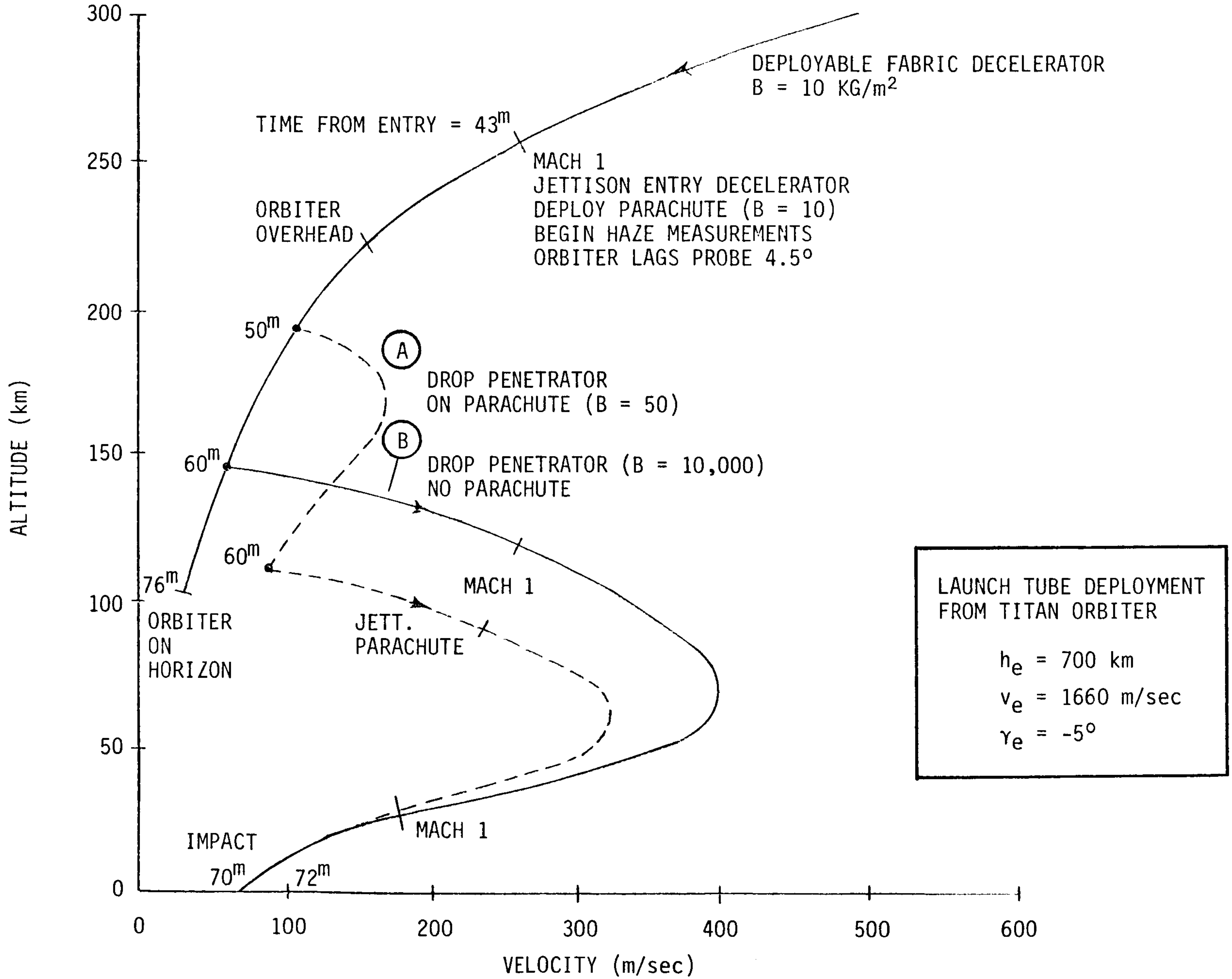
HOT AIR BALLOON PERFORMANCE AT TITAN
(FREE CONVECTION AND RADIATIVE HEAT TRANSFER)



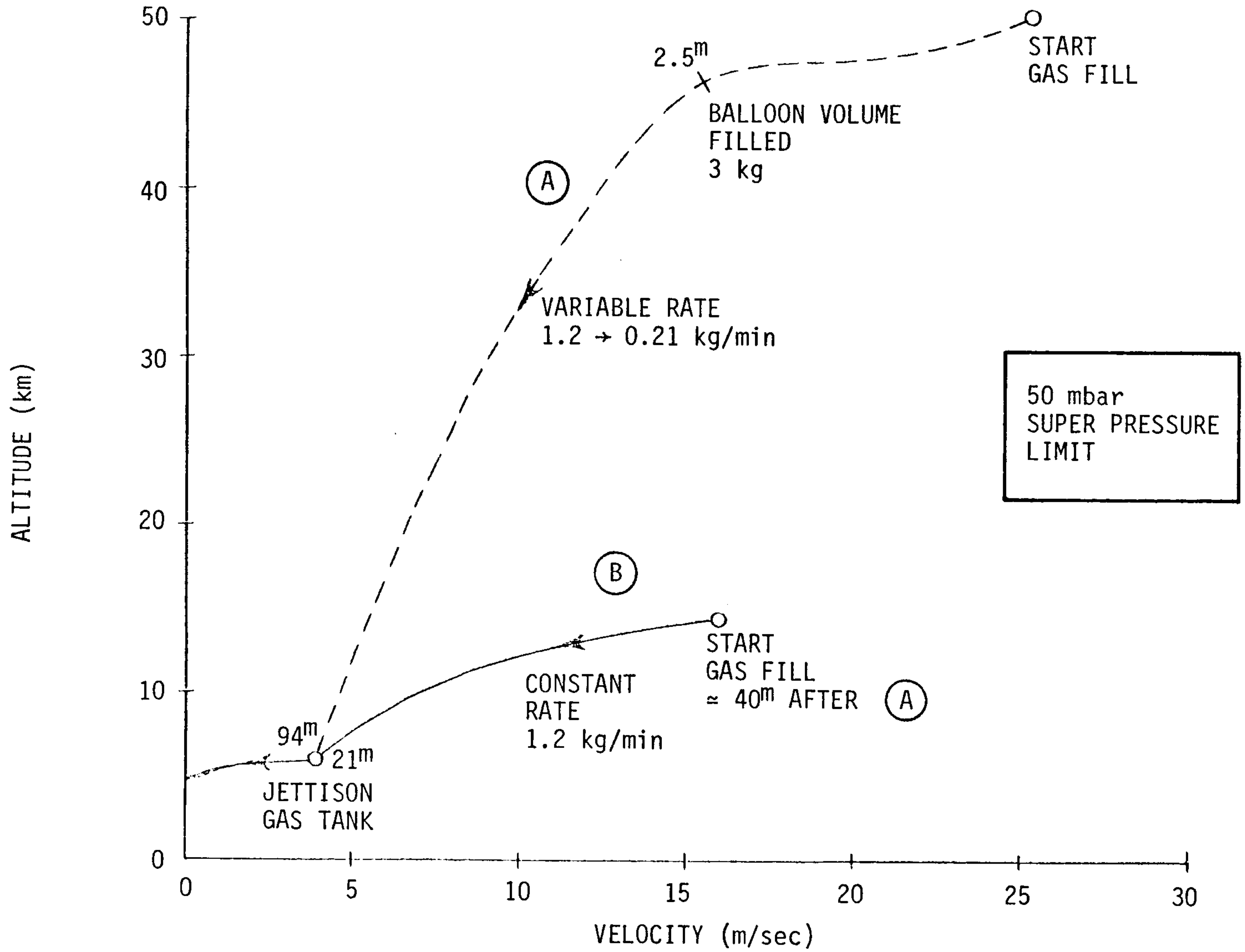
EFFECT OF FORCED CONVECTION



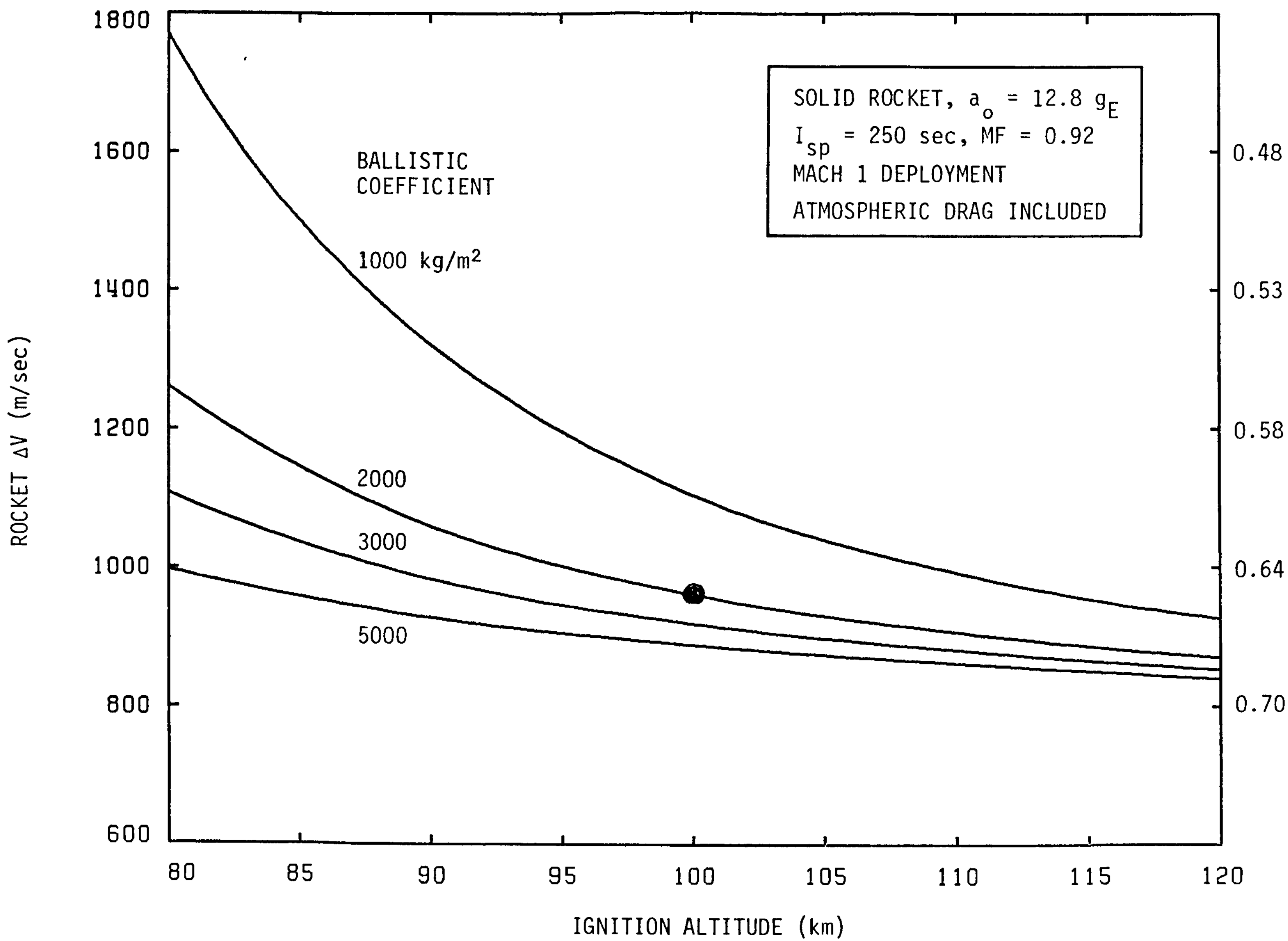
COMPARISON OF TITAN BUOYANT STATION CONCEPTS FOR 300 KG PAYLOAD



DESCENT PROFILE FOR COMBINED HAZE/PENETRATOR PROBE CONCEPT



COMPARISON OF BUOYANT STATION GAS FILL MODES



SOUNDING ROCKET PROBE TO UPPER HAZE LAYER (h_{MAX} = 250 km)

EFFECT OF SATURN GRAVITY PERTURBATIONS ON TITAN ORBITER STABILITY

INITIAL PERIAPSE ALTITUDE = 1000 km

WORST CASE PERIAPSE LOCATION ($\omega = 45°$)

TIME	PERIAPSE ALTITUDE VARIATION (km)				
	$P = 24^h$, $i = 0°$	$P = 12^h$, $i = 0°$	$P = 6^h$, $i = 0°$	$P = 6^h$, $i = 90°$	CIRCULAR ORBIT
0	1000	1000	1000	1000	1000
1^d	448	849	975	975	↓
2^d	51	757	962	955	↓
3^d	CRASH	768	968	945	NO CHANGE
4^d		878	989	944	
5^d		1032	1014	943	
6^d		1146	1029	935	
7^d		1150	1024	917	
8^d		1042	1003	891	

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SMALL BALLOON.............50 KM ALTITUDE, 45^{o} LATITUDE, 35 M/S OVER SURFACE
80 BPS SCIENCE DATA ACCUMULATION
CROSS DIPOLE ANTENNA (3 DB GAIN)
1 OR 10 WATT TRANSMITTER POWER @ 1387 MH_Z
800 TO 12,800 BPS TRANSMISSION RATE

LARGE BUOYANT STATION.....5 KM ALTITUDE, 0^{o} LATITUDE, 7 M/S OVER SURFACE
1200 BPS SCIENCE DATA ACCUMULATION
CROSS DIPOLE
1 OR 10 WATTS
800 TO 12,800 BPS

ORBITER...................1000 KM CIRCULAR (3.93^{h}) OR 1000 X 3328 KM (6^{h})
POLAR OR EQUATORIAL INCLINATIONS
CROSS DIPOLE (3 DB) OR PARABOLIC TRACKING ANTENNA (22 DB, 12.6^{o})

REQUIRED DATA MARGIN = 3 DB

RETRANSMIT TO EARTH AT ≈ 10,000 BPS

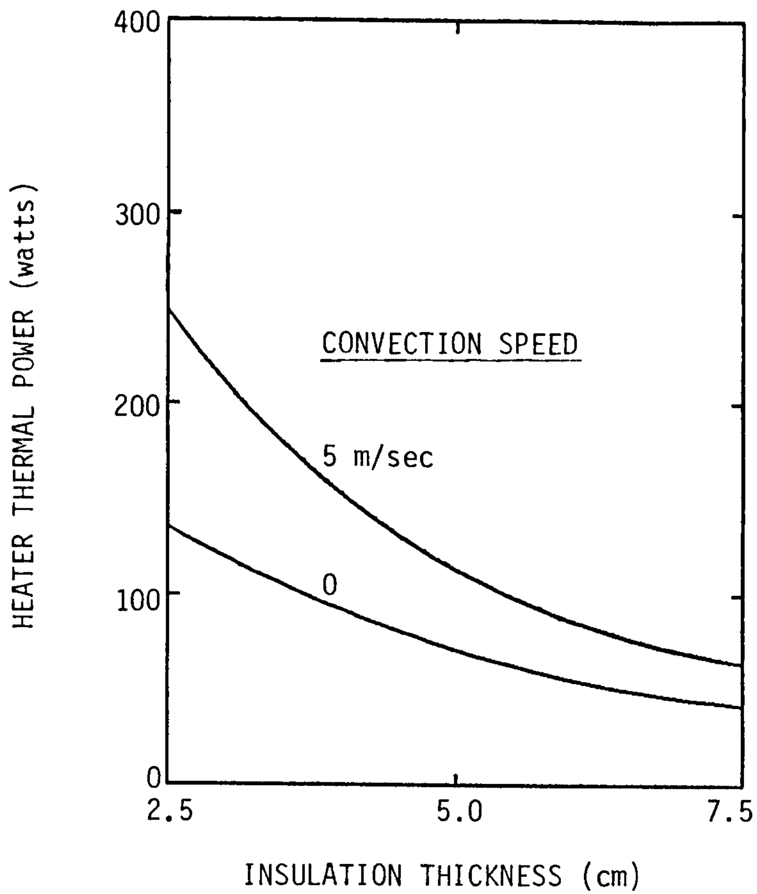
RELAY COMMUNICATIONS SUMMARY

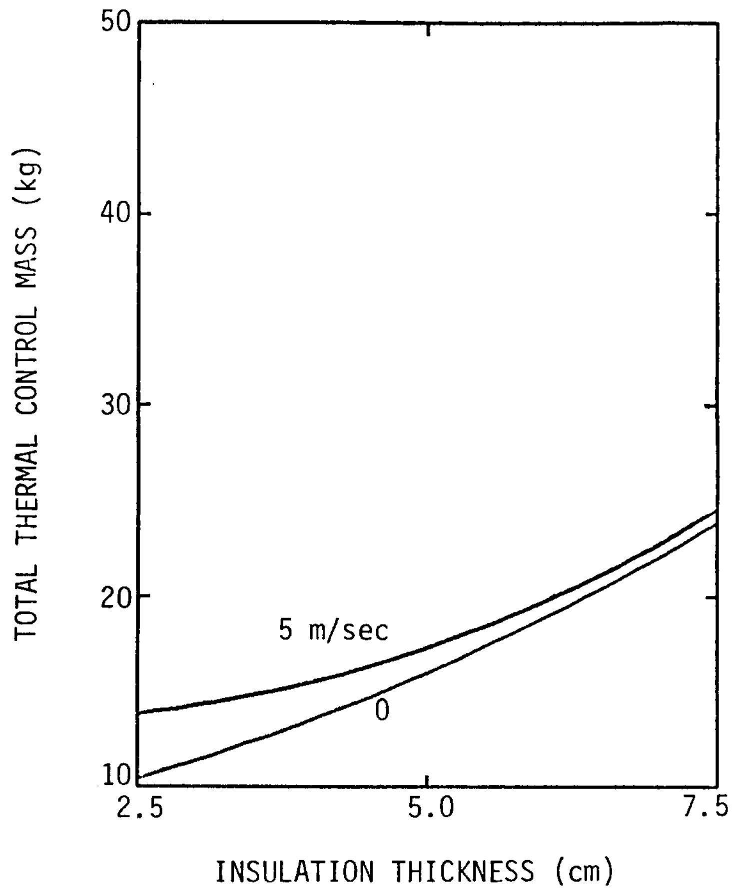
1000 KM, CIRCULAR, POLAR ORBIT
PERIOD = 3.93 HOURS

	SMALL BALLOON 50 KM, 45° LAT.		BUOYANT STATION 5 KM, 0° LAT.
SCIENCE DATA (BITS/ORBIT)	1.1×10^6		17×10^6
TRANSMISSION RATE (BITS/SEC)	800		12,800
TRANSMITTER POWER (WATTS)	1		1
ORBITER ANTENNA	CROSS DIPOLE	TRACKING	TRACKING
BALLOON VISIBILITY (ORBITS)	14/19	14/19	30/60
MIN. TRANSMISSION TIME (MINUTES)	13	31	17
MAX. TRANSMISSION TIME (MINUTES)	48	55	56
MAX. DATA STORAGE (BITS)	4.3×10^6	3.4×10^6	262×10^6
MAX. DATA TRANSMISSION (BITS)	2.3×10^6	2.6×10^6	43×10^6
MAX. RETRANSMIT TIME @ 10^4 BPS (HOURS)	0.06	0.07	1.19

FIBERGLASS INSULATION..........200 kg/m^3

RTG WASTE HEAT USAGE...........0.03 kg/w_t





STEADY STATE THERMAL CONTROL REQUIREMENTS FOR SMALL BALLOON PAYLOAD

AMBIENT CONDITIONS

$h = 50$ km

$T = 75$ K

PAYLOAD COMPARTMENT

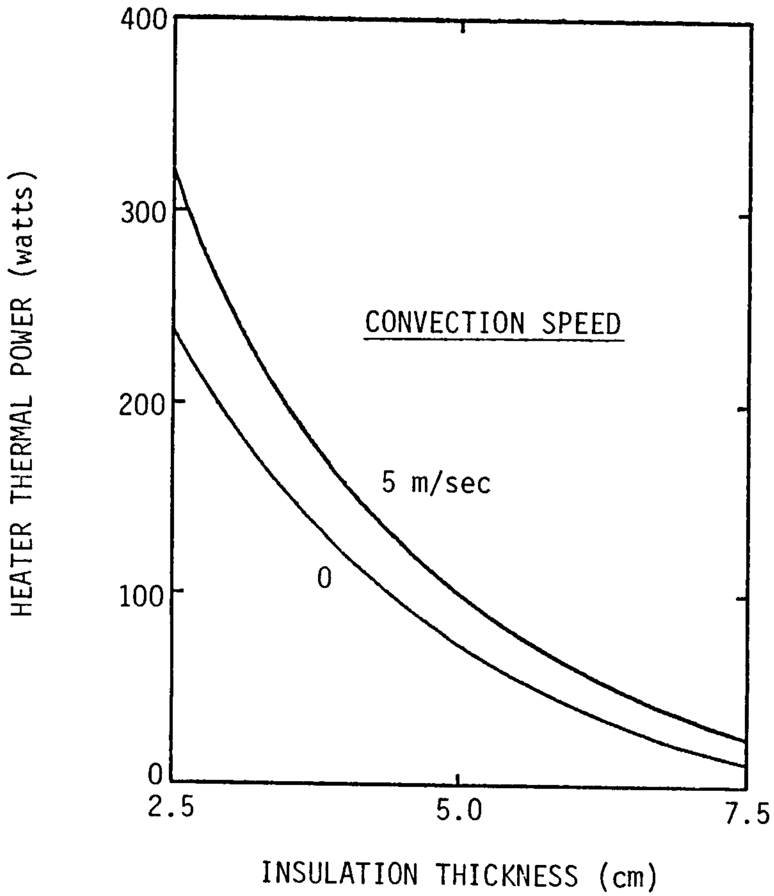
$A_s = 1.2\ m^2$

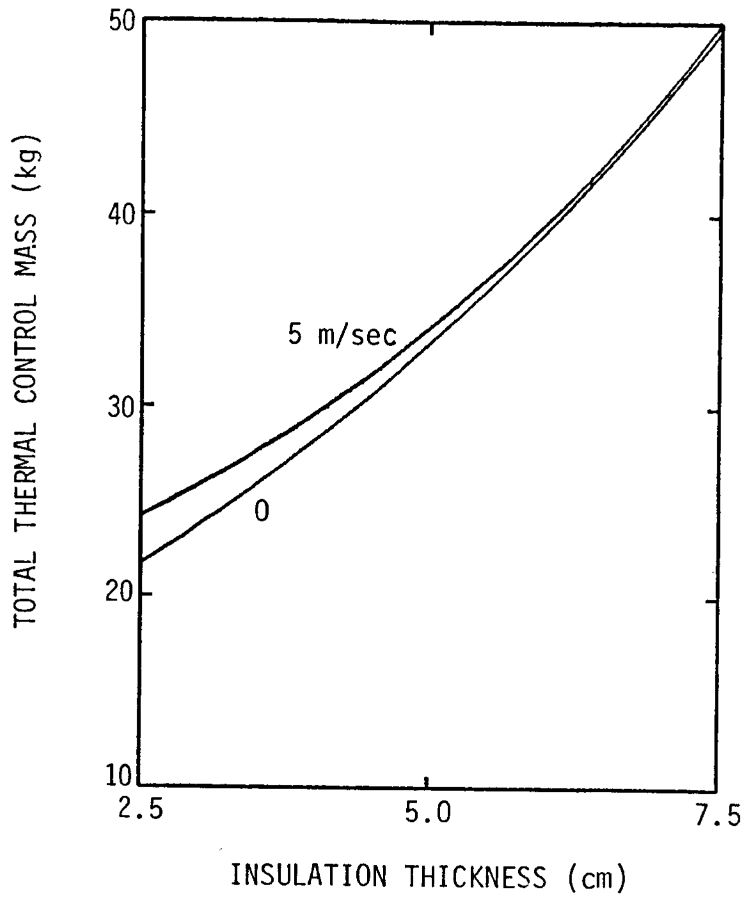
$T = 41^\circ$ F

$P = 50$ watts

$AK = 0.025\ \frac{w \cdot m}{K}$ (PENETRATIONS)

FIBERGLASS INSULATION..........200 kg/m^3
RTG WASTE HEAT USAGE...........0.03 kg/w_t





STEADY STATE THERMAL CONTROL REQUIREMENTS FOR LARGE BALLOON PAYLOAD

AMBIENT CONDITIONS

$h = 5$ km
$T = 92$ K

PAYLOAD COMPARTMENT

$A_s = 2.7\ m^2$
$T = 41^\circ$ F
$P = 140$ watts
$AK = 0.025\ \frac{w \cdot m}{K}$ (PENETRATIONS)

TITAN ORBITER MASS BREAKDOWN

SUBSYSTEM	NON-IMAGING ORBITER	IMAGING ORBITER
STRUCTURE & DEVICES	211.6 kg	
THERMAL, CABLING & PYRO	68.8	
ATTITUDE & ARTICULATION	65.7	
TELECOMMUNICATIONS	45.4	
COMMAND & DATA HANDLING	37.9	
REACTION CONTROL	39.9	
POWER	77.5	
ENGINEERING SUBTOTAL	546.8	546.8
SCIENCE	55.0	125.0
	601.8	671.8
CONTINGENCY (10%)	60.2	67.2
SUBTOTAL (W/O PROPULSION & PROBE SUPPORT)	662.0 kg	739.0 kg
	(741.0)*	

* WITH NEP INTEGRATION
ADDED SHIELDING & RCS, LESS RTG

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TITAN FLYBY PROBE CARRIER MASS BREAKDOWN

SUBSYSTEM	1 LARGE OR 3 SMALL PROBES	1 LARGE & 3 SMALL PROBES
STRUCTURE & DEVICES	161 kg	191 kg
THERMAL, CABLING & PYRO	52	60
ATTITUDE CONTROL	17	17
TELECOMMUNICATIONS	21	21
COMMAND & DATA HANDLING	30	30
POWER	94	94
ENGINEERING SUBTOTAL	375	413
CONTINGENCY (10%)	38	41
SUBTOTAL (W/O PROPULSION & PROBE SUPPORT)	413 kg	454 kg

BUOYANT STATION PROBE MASS BREAKDOWN

STATION SUBSYSTEM	50 km SMALL BALLOON	5 km LARGE BALLOON		5 km LARGE BLIMP
SCIENCE	20 kg	80 kg		80 kg
STRUCTURE & DEVICES	28	72		85
THERMAL CONTROL & CABLING	12	20		25
TELECOMMUNICATIONS	11	11		11
COMMAND & DATA	14	23		23
POWER & HEAT SOURCE *	15	74 *		102 *
PROPULSION	—	—		14
TETHER SYSTEM	—	—		20
Δ FOR DROPPED PACKAGE	—	20		—
TOTAL STATION PAYLOAD	100	300		360
H_2 BUOYANT GAS	10	27		32
RESERVE GAS & TANK	5	11		15
BALLOON FABRIC (DIAMETER)	12 (8.2 m)	6	(5.2 m)	7 (11.9 x 4 m)
TOTAL FLOATED MASS	127	344		414
GAS TRANSPORT	90	243		288
SOUNDING ROCKET & PAYLOAD	—	—	(60)	—
TOTAL ENTRY PAYLOAD	217	587	(647)	702
AERODECELERATION MODULE	79	178	(219)	219
TOTAL ENTRY PROBE MASS	296 kg	765 kg	(866 kg)	921 kg

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SONAR BUOY TECHNOLOGY

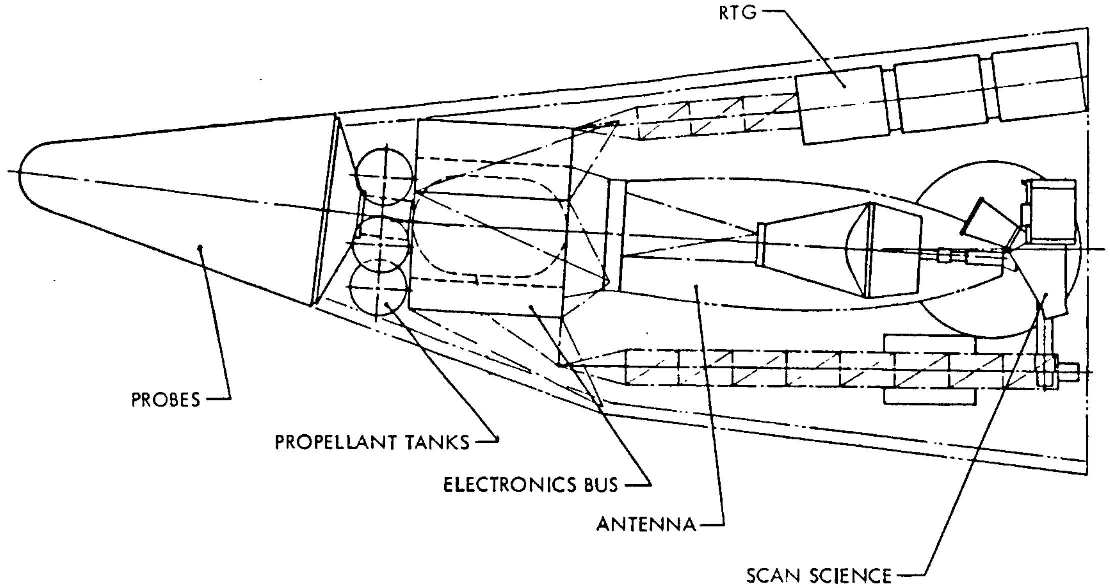
- SONAR TECHNOLOGY HAS ATTAINED A VERY ADVANCED STATE OF DEVELOPMENT IN RECENT YEARS WITH REGARD TO LIGHTWEIGHT PACKAGING, RANGE OF PERFORMANCE, AND INTERPRETATION OF ACOUSTIC SIGNAL RETURN.
- SMALL PASSIVE SYSTEMS (INCLUDING STRUCTURE AND TELEMETRY) HAVE BEEN BUILT IN THE WEIGHT RANGE 2 TO 5 KG.
- ACTIVE SYSTEMS WEIGHING 13 TO 18 KG HAVE BEEN DEPLOYED. MOST OF THIS WEIGHT IS FOR BATTERIES PROVIDING AN 8 HOUR LIFETIME.
- DEPTH SOUNDING TO GREATER THAN 1 KM IS READILY ACHIEVED.
- EXPLOSIVE CHARGES (1 OZ PER SOUNDING) ARE USED TO ENHANCE THE PASSIVE OPTION.
- HYDRAPHONE TRANSDUCER DESIGNS HAVE BEEN TESTED IN LIQUID HELIUM.
- FOR TITAN 'OCEANOGRAPHY', MEASUREMENTS OF INTEREST INCLUDE DEPTH, SPEED OF SOUND, ROUGHNESS OF BOTTOM, SEDIMENT STRATIFICATION, AND POSSIBLY SEISMIC ACTIVITY.
- BACKGROUND NOISE LEVEL (SURFACE AGITATION, BOILING, SEISMIC ACTIVITY) AND ACOUSTIC LOSSES IN LIQUID HYDROCARBONS ARE AREAS OF PRESENT UNCERTAINTY FOR TITAN APPLICATIONS.

TITAN INTENSIVE STUDY - HARDWARE MASS ELEMENTS (KG) EXCLUDING MAIN PROPULSION

REFERENCE MISSION CONCEPT

	1	2	3	4	5
TITAN ORBITER					
ORBITER WITH SCIENCE	662	739	739	739	741
PROBE LAUNCH SYSTEMS	45	45	0	45	147
PROBE SYSTEMS	300	300	0	240	1809
	1007	1084	739	1024	2697
TITAN PROBE (B.S.) CARRIER					
CARRIER BUS (NO SCIENCE)	0	413	454	454	0
PROBE LAUNCH SYSTEMS	0	45	80	80	0
PROBE SYSTEMS	0	888	1754	1809	0
	0	1346	2288	2343	0
	1007	2430	3027	3367	2697

AEROCAPTURE VEHICLE FOR TITAN ORBIT INSERTION



INBOARD
PROFILE
EXAMPLE
ONLY

AEROSHELL STRUCTURE............129 KG (6.3 x 2.7 meters)

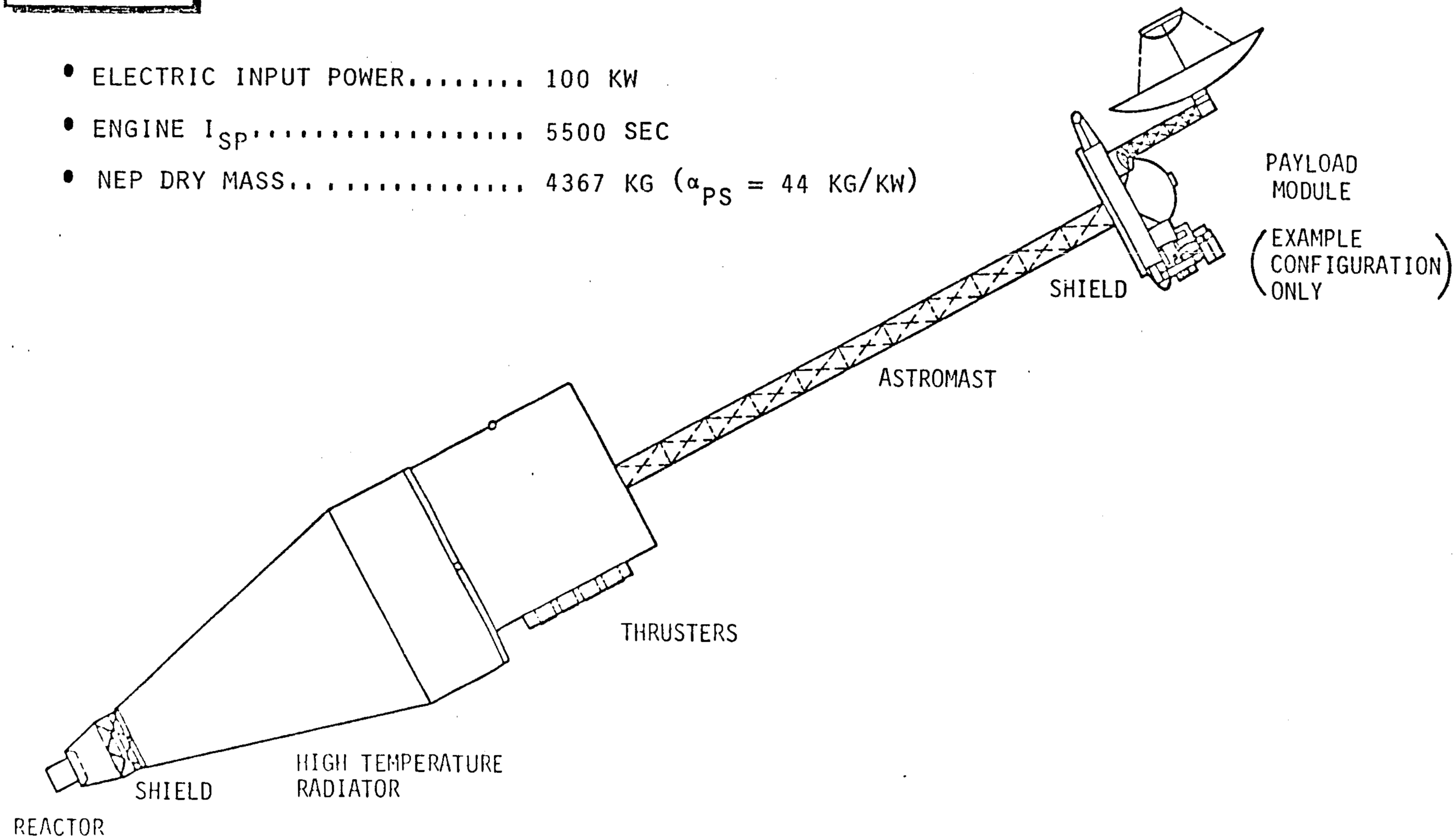
THERMAL PROTECTION SYSTEM......343

CONTROL SYSTEMS............... 51

523 KG (OUTBOARD)

NEP

- ELECTRIC INPUT POWER........ 100 KW
- ENGINE I_{SP}.................. 5500 SEC
- NEP DRY MASS.............. 4367 KG (α_{PS} = 44 KG/KW)



REFERENCE MISSION PROFILES

PROFILE DATA FOR TITAN MISSION CONCEPT #1

	1st LAUNCH	2nd LAUNCH
HARDWARE ELEMENTS	NON-IMAGING ORBITER LTD HAZE/PENETR. PROBES (3) AEROCAPTURE VEHICLE	
LAUNCH STAGE	OOA CENTAUR(G')/STAR 48	
FLIGHT MODE	DIRECT BALLISTIC, AEROCAPTURE	
LAUNCH DATE	JULY 1999	
FLIGHT TIME	4.5 YEARS	
ARRIVAL TIME	JAN 2004	
OPERATING TIME	6 MONTHS	
TOTAL INJECTED MASS	1865 KG	
INJECTED MASS MARGIN	140 KG (@ C_3 = 115)	

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COST ESTIMATE FOR TITAN MISSION CONCEPT #1

FY'84 $M

	TITAN ORBITER	HAZE/PENETRATORS(3)	AEROCAPTURE VEHICLE	TOTAL
PROJECT MANAGEMENT	12.9	9.5	6.3	28.7
SCIENCE DEVELOPMENT	67.2	46.5	—	113.7
SUBSYSTEMS DEVELOP	66.1	50.4	59.3	175.8
SYSTEM INTEG/TEST	37.4	27.1	27.8	92.3
RTG's	14.0	9.5	—	23.5
TOTAL	197.6	143.0	93.4	434.0
SUBCONTRACTING		*	*	35.5
VEHICLE INTEG				17.0
OPERATIONS				61.4
DATA ANALYSIS				15.0
PROGRAM MGMT				4.7
NET TOTAL				567.6
CONTINGENCY (30%)				170.3
GRAND TOTAL				737.9

SHUTTLE AND CENTAUR LAUNCH COSTS NOT INCLUDED

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PROFILE DATA FOR TITAN MISSION CONCEPT #2

	1st LAUNCH	2nd LAUNCH
HARDWARE ELEMENTS	IMAGING ORBITER LTD HAZE/PENETR. PROBES (3) AEROCAPTURE VEHICLE	SMALL BALLOON ENTRY PROBES (3) PROBE CARRIER
LAUNCH STAGE	OOA CENTAUR(G')/STAR 48	SHUTTLE/CENTAUR(G')/STAR 48
FLIGHT MODE	DIRECT BALLISTIC, AEROCAPTURE	DIRECT BALLISTIC, FLYBY
LAUNCH DATE	JULY 1999	JULY 2000
FLIGHT TIME	4.5 YEARS	4.2 YEARS
ARRIVAL TIME	JAN 2004	SEP 2004
OPERATING TIME	9 MONTHS	1 MONTH
TOTAL INJECTED MASS	1960 KG	1570 KG
INJECTED MASS MARGIN	45 KG* (@ C_3 = 115)	75 KG* (@ C_3 = 112)

* NEXT CAPABLE LAUNCH STAGE
WOULD INCREASE MARGINS SUBSTANTIALLY

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COST ESTIMATE FOR TITAN MISSION CONCEPT #2

FY'84 $M

	TITAN ORBITER	HAZE PENETRATORS(3)	AEROCAP VEHICLE	SUBTOTAL	PROBE CARRIER	BALLOON PROBE(3)	SUBTOTAL	TOTAL
PROJECT MANAGEMENT	15.5	9.5	6.3	31.3	6.5	11.0	17.5	48.8
SCIENCE DEVELOPMENT	93.5	46.5	—	140.0	—	42.5	42.5	182.5
SUBSYSTEMS DEVELOP	66.2	50.4	59.3	175.9	62.5	70.4	132.9	308.8
SYSTEM INTEG/TEST	45.2	27.1	27.8	100.1	19.2	31.6	50.8	150.9
RTG's	14.0	9.5	—	23.5	13.0	13.0	26.0	49.5
TOTAL	234.4	143.0	93.4	470.8	101.2	168.5	269.7	740.5
SUBCONTRACTING		*	*	35.5	*	*	40.5	76.0
VEHICLE INTEG				18.9			9.0	27.9
OPERATIONS				67.6			16.7	84.3
DATA ANALYSIS				25.0			5.0	30.0
PROGRAM MGMT				5.3			2.7	8.0
NET TOTAL				623.1			343.6	966.7
CONTINGENCY (30%)				186.9			103.1	290.0
GRAND TOTAL				810.0			446.7	1256.7

SHUTTLE AND CENTAUR LAUNCH COSTS NOT INCLUDED

PROFILE DATA FOR TITAN MISSION CONCEPT #3

	1st LAUNCH	2nd LAUNCH
HARDWARE ELEMENTS	IMAGING ORBITER AEROCAPTURE VEHICLE	LARGE BALLOON(W/ROCKET) ENTRY PROBE SMALL BALLOON ENTRY PROBES (3) PROBE CARRIER
LAUNCH STAGE	SHUTTLE/CENTAUR(G')/STAR 48	OOA CENTAUR(G')/CENTAUR(G)
FLIGHT MODE	DIRECT BALLISTIC, AEROCAPTURE	DIRECT BALLISTIC, FLYBY
LAUNCH DATE	JULY 1999	JULY 2000
FLIGHT TIME	4.5 YEARS	4.2 YEARS
ARRIVAL TIME	JAN 2004	SEP 2004
OPERATING TIME	10 MONTHS	2 MONTHS
TOTAL INJECTED MASS	1540 KG	2660 KG
INJECTED MASS MARGIN	80 KG (@ C_3 = 115)	1040 KG (@ C_3 = 112)

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COST ESTIMATE FOR TITAN MISSION CONCEPT #3

FY'84 $M

	TITAN ORBITER	AEROCAP VEHICLE	SUBTOTAL	PROBE CARRIER	SMALL BALLOON PROBE(3)	LARGE BALLOON PROBE	SOUNDING ROCKET	SUBTOTAL	TOTAL
PROJECT MANAGEMENT	15.3	6.3	21.6	7.1	11.0	13.9	5.1	37.1	58.7
SCIENCE DEVELOPMENT	93.5	—	93.5	—	42.5	71.7	30.1	144.3	237.8
SUBSYSTEMS DEVELOP	64.1	59.3	123.4	68.9	70.4	69.8	22.4	231.5	354.9
SYSTEM INTEG/TEST	44.6	27.8	72.4	21.1	31.6	40.9	13.9	107.5	179.9
RTG's	14.0	—	14.0	13.0	13.0	10.0	—	36.0	50.0
TOTAL	231.5	93.4	324.9	110.1	168.5	206.3	71.5	556.4	881.3
SUBCONTRACTING		*	14.0	*	*	*	*	83.5	97.5
VEHICLE INTEG			11.8					23.6	35.4
OPERATIONS			59.5					35.4	94.9
DATA ANALYSIS			22.0					17.0	39.0
PROGRAM MGMT			3.9					5.9	9.8
NET TOTAL			436.1					721.8	1157.9
CONTINGENCY (30%)			130.8					216.5	347.3
GRAND TOTAL			566.9					938.3	1505.2

SHUTTLE AND CENTAUR LAUNCH COSTS NOT INCLUDED

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PROFILE/COST COMPARISON OF TWO FLIGHT MODES FOR TITAN MISSION CONCEPT #3

	DIRECT BALLISTIC	ΔVEGA BALLISTIC
1st LAUNCH (ORBITER) SYSTEM	SHUTTLE/CENTAUR (G')/STAR 48	SHUTTLE/CENTAUR(G')
2nd LAUNCH (PRB. CARRIER) SYSTEM	OOA CENTAUR(G')/CENTAUR(G)	SHUTTLE/CENTAUR(G')
TITAN ORBIT CAPTURE MODE	AEROCAPTURE	EARTH-STORABLE RETROPROPULSION
FLIGHT TIMES	4.5 AND 4.2 YEARS	7.5 AND 7.2 YEARS
1st LAUNCH-TO-END OF MISSION	5.4 YEARS	8.4 YEARS
TOTAL INJECTED MASS	1540 KG 2660 KG	4260 KG 3200 KG
INJECTED MASS MARGIN	80 KG (@ C_3 = 115) 1040 KG (@ C_3 = 112)	40 KG (@ C_3 = 50) 1100 KG (@ C_3 = 50)
PROJECT COST (FY'84 $)	1,510 $M	1,390 $M

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PROFILE DATA FOR TITAN MISSION CONCEPT #4

	1st LAUNCH	2nd LAUNCH
HARDWARE ELEMENTS	IMAGING ORBITER LTD HAZE PROBES (3) AEROCAPTURE VEHICLE	LARGE BLIMP ENTRY PROBE SMALL BALLOON ENTRY PROBES (3) PROBE CARRIER
LAUNCH STAGE	OOA CENTAUR(G')/STAR 48	OOA CENTAUR(G')/CENTAUR(G)
FLIGHT MODE	DIRECT BALLISTIC, AEROCAPTURE	DIRECT BALLISTIC, FLYBY
LAUNCH DATE	JULY 1999	JULY 2000
FLIGHT TIME	4.5 YEARS	4.2 YEARS
ARRIVAL DATE	JAN 2004	SEP 2004
OPERATING TIME	10 MONTHS	2 MONTHS
TOTAL INJECTED MASS	1885 KG	2730 KG
INJECTED MASS MARGIN	120 KG (@ C_3 = 115)	970 KG (@ C_3 = 112)

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COST ESTIMATE FOR TITAN MISSION CONCEPT #4

FY'84 $M

	TITAN ORBITER	HAZE DEVICE(3)	AEROCAP VEHICLE	SUBTOTAL	PROBE CARRIER	BALLOON PROBE(3)	BLIMP PROBE	SUBTOTAL	TOTAL
PROJECT MANAGEMENT	15.5	7.9	6.3	29.7	7.1	11.1	14.3	32.4	62.1
SCIENCE DEVELOPMENT	93.5	38.4	—	131.9	—	42.5	71.7	114.2	246.1
SUBSYSTEMS DEVELOP	66.2	43.3	59.3	168.8	68.9	70.4	74.0	213.3	382.1
SYSTEM INTEG/TEST	45.2	22.4	27.8	95.4	21.1	31.6	42.0	94.7	190.1
RTG's	14.0	—	—	14.0	13.0	13.0	10.0	36.0	50.0
TOTAL	234.4	112.0	93.4	439.8	110.1	168.5	212.0	490.6	930.4
SUBCONTRACTING		*	*	30.8	*	*	*	73.6	104.4
VEHICLE INTEG				17.8				19.8	37.6
OPERATIONS				67.0				31.2	98.2
DATA ANALYSIS				24.0				15.0	39.0
PROGRAM MGMT				5.1				5.2	10.3
NET TOTAL				584.5				635.4	1219.9
CONTINGENCY (30%)				175.4				190.6	366.0
GRAND TOTAL				759.9				826.0	1585.9

SHUTTLE AND CENTAUR LAUNCH COSTS NOT INCLUDED

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PROFILE DATA FOR TITAN MISSION CONCEPT #5

	1st LAUNCH	2nd LAUNCH
HARDWARE ELEMENTS	NON-IMAGING ORBITER LARGE BLIMP ENTRY PROBE SMALL BALLOON ENTRY PROBES (3) NEP VEHICLE	
LAUNCH STAGE	00A CENTAUR(G')	
FLIGHT MODE	LOW THRUST, NO ESCAPE SPIRAL	
LAUNCH DATE	MAY 2000	
FLIGHT TIME	4.6 YEARS	
ARRIVAL TIME	DEC 2004	
OPERATING TIME	6 MONTHS	
TOTAL INJECTED MASS	12,600 KG	
INJECTED MASS MARGIN	800 KG (@ C_3 = 9)	

COST ESTIMATE FOR TITAN MISSION CONCEPT #5

FY'84 $M

	TITAN ORBITER	BALLOON PROBE(3)	BLIMP PROBE	TOTAL
PROJECT MANAGEMENT	14.6	11.0	14.3	39.9
SCIENCE DEVELOPMENT	67.2	42.5	71.7	181.4
SUBSYSTEMS DEVELOP	83.7	70.7	74.2	228.6
SYSTEM INTEG/TEST	42.7	31.7	42.1	116.5
RTG's	—	13.0	10.0	23.0
TOTAL	208.2	168.9	212.3	589.4
SUBCONTRACTING		*	*	57.2
VEHICLE INTEG				41.4
OPERATIONS				100.5
DATA ANALYSIS				27.0
PROGRAM MGMT				8.0
NET TOTAL				823.5
CONTINGENCY (30%)				247.1
GRAND TOTAL				1070.6

SHUTTLE, CENTAUR, AND NEP COSTS NOT INCLUDED

COST COMPARISON OF TITAN MISSION CONCEPTS

FY'84 $M

REFERENCE MISSION CONCEPT

	1*	2	3	4	5
HARDWARE DEVELOP./INTEG.					
ORBITER SYSTEMS	492	532	355	494	696
PROBE CARRIER SYSTEMS	0	322	669	589	0
MISSION OPERATIONS	61	84	95	98	100
DATA ANALYSIS	15	30	39	39	27
NET TOTAL	568	968	1,158	1,220	823
CONTINGENCY (30%)	172	292	352	370	247
TOTAL	740	1,260	1,510	1,590	1,070

LAUNCH AND UPPER STAGE COSTS NOT INCLUDED

* NO BUOYANT STATIONS IN CONCEPT 1

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